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16. ABSTRACT

The major objective of this study was to operate a full-scale single-stage nitrification-denitrification plant without methanol addition to determine the feasibility and reliability of the process, the design features needed to be incorporated by engineers, and the operating techniques to be employed to ensure optimum performance. Because nitrification-denitrification can become more difficult to operate under extreme cold wastewater temperatures, a full-scale plant located at Owego, New York, was selected which performs under wastewater temperatures ranging from 0° to 22°C. Alternating aerobic-anoxic conditions were achieved in completely mixed reactors by the on-off cycling of mechanical aerators.

The following results and conclusions were determined from these studies:

1. Single-stage nitrification-denitrification is a viable nitrogen removal process,
2. Nitrogen removals of from 76 to 86 percent were normally accomplished with hydraulic retention times of 13 to 27 hours, depending upon wastewater temperature and strength. BOD and suspended solids reductions were well above 90 percent.

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FULL-SCALE OPERATION OF A SINGLE-STAGE NITRIFICATION-DENITRIFICATION PLANT

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The work reported herein shows that by modification of operational control a large degree of total nitrogen removal can be obtained at municipal wastewater treatment facilities. The report highlights those features of plant design and operational control necessary to obtain nitrogen removal in a single-stage activated sludge plant treating normal strength domestic wastewater.

Francis T. Mayo, Director
Municipal Environmental Research
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ABSTRACT

The major objective of this study was to operate the single-stage nitrification-denitrification process on a full-scale to determine the feasibility and reliability of the process, the design features needed and the operating techniques to ensure optimum performance. Because nitrification-denitrification can become difficult to operate under extremely cold wastewater temperatures, a full-scale plant at Owego, New York, was selected where wastewater temperatures range from 8° to 22°C. Alternating aerobic-anoxic conditions were achieved in completely mixed reactors by the on-off cycling of mechanical aerators.

The following results and conclusions were determined from these studies:

1. Nitrogen removals of from 76 to 86 percent were normally accomplished with hydraulic retention times of 13 to 27 hours, depending upon wastewater temperature and strength. BOD and suspended solids reductions were well above 90 percent.
2. Wastewater organics were found to be a suitable carbon source for the denitrification process in lieu of supplemental carbon addition.
3. Solids inventory must be reduced at higher temperatures to prevent premature carbon consumption and subsequent reductions in denitrification efficiency. Nitrogen removal was reduced to 67 percent for a 2- to 3-week period during summer operation because of excessive solids inventory but was restored immediately by reducing the solids inventory.
4. Strong supernatant returns resulting from an outage of one anaerobic digester and excessive storage of solids in the one remaining digester adversely affected the nitrification-denitrification process. Because of these strong supernatant returns, nitrogen removal was reduced to 58 percent during the last month of the study.
5. Sludge settling rates measured during the study showed no differences in settleability compared to both conventional and extended aeration operation that preceded the study.
6. Less power is consumed than for single-stage nitrification only.
7. Nitrogen removal can be achieved in many existing plants at little or no capital cost by implementing single-stage nitrification-denitrification if the design conditions and wastewater character lend themselves to the control option studied at Owego, New York.

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Analytical services were provided by Water Testing Laboratory, Inc., supervised by Mr. Michael P. Quirk. Bradford G. Wheler of Stearns & Wheler, Civil and Sanitary Engineers, participated in much of the field work and data analysis.

Monitoring equipment, including specific ion probes and meter, was loaned for field testing to the Town of Owego by Orion Research, Inc.

SECTION 1

INTRODUCTION

In many areas of the United States, water quality criteria require the removal of nutrients from wastewater treatment plant effluents. Nitrogen and phosphorus are the two major nutrients of concern in wastewater effluents. This study was addressed to improving nitrogen removal at an existing activated sludge plant by modification of operational control.

Nitrogen removal facilities can cost considerably more to construct and operate as compared to conventional secondary treatment. This increased cost is largely due to the fact that the most reliable biological system available necessitates three separate stages of activated sludge treatment (2, 5, 10), with different types of process control in each of the three stages. Additionally, methanol must be added to multi-stage systems for nitrogen removal. Within the past two years the energy situation has resulted in methanol shortages and much higher costs.

Recent research (3, 4) has indicated that the functions of the three different stages can be combined in a single treatment stage under controlled operating conditions, and can achieve 75 percent or more nitrogen removal without the addition of methanol. However, there is a lack of detailed design and operating data for engineers and operators to implement single-stage nitrification-denitrification. It was the major objective of this study to operate a full-scale plant to determine the feasibility and reliability of the process, to identify design features needed to be incorporated by engineers, and to develop operating techniques to ensure optimum performance. Process and operational variables that warrant study are listed in Table 1. Because nitrification-denitrification can become more difficult to operate under extremely cold wastewater temperatures, a full-scale plant at Oswego, New York, was selected which performs under wastewater temperatures ranging from 8° to 22°C.

TABLE 1. SINGLE-STAGE NITRIFICATION-DENITRIFICATION PROCESS AND OPERATIONAL VARIABLES

Wastewater Temperature	Food/Mass (F/M)
Nitrification and Denitrification Kinetics	Solids Retention Time
COD/TKN	Dissolved Oxygen Ranges
Hydraulic Retention Time	Aerobic-Anoxic Cycling Time
Sludge Recycle Rate	Aeration Tank Volume
Sludge Wasting Rate	Sludge Settling Properties
MLSS and MLVSS	

For the initial portion of the study, operation as extended aeration activated sludge was chosen because the longer aeration time associated with this variation of the activated sludge process is more conducive to success of single-stage nitrification-denitrification. The plant selected, however, is capable of operation at shorter detention periods; therefore, these shorter periods were also investigated under various conditions.

An additional reason for initial operation under the extended aeration process was that there are many extended aeration plants in the nation which have the capability for nitrification and denitrification, and furthermore, many such plants are under design or construction. Thus, a significant improvement in national water quality could be achieved at very little cost by the use of single-stage nitrification-denitrification, especially in water quality limited areas where nitrogen removal is necessary.

SECTION 2

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. Single-stage nitrification-denitrification, using an intermittently aerated compartment followed by a continuously aerated compartment, normally provided total nitrogen removals of 76 to 86 percent under wastewater temperatures varying from 8° to 22°C. BOD and suspended solids reductions of well over 90 percent were simultaneously obtained. It is believed that similar performance can be obtained in many other similarly designed plants by a few simple physical and operational changes.

2. The process was operated under the wide influent load variations found in smaller plants. The absence of primary settling and the presence of significant shock loads from septic tank trucks and river siphon flushings did not adversely affect process operation and performance.

3. At wastewater temperatures ranging from 11° to 22°C, successful operation was achieved at F/M ratios of 0.06 to 0.13 g BOD_5/day/g MLVSS and solids retention times of 13 to 70 days. At temperatures of 8° to 12°C, F/M ratios of 0.07 to 0.08 g BOD_5/day/g MLVSS and solids retention times of 20 to 32 days were successfully utilized. Generally, these corresponded to hydraulic retention times of 13 to 27 hours at the higher temperatures and 20 to 24 hours at the low temperatures.

4. Wastewater organics were suitable as a carbon source for denitrification. However, at higher wastewater temperatures it was necessary to significantly reduce the mixed liquor suspended solids inventory to prevent premature carbon consumption and loss of denitrification. Nitrogen removal was reduced to 67 percent for a 2- to 3-week period during summer operation because of excessive solids inventory but was restored immediately by reducing the solids inventory.

5. Strong digester supernatant returns resulting from an outage of one anaerobic digester and excessive storage of solids in the one remaining digester occurred during that portion of the test program when colder wastewater was being treated. The return of excessive digester solids necessitated an increase in the sludge wasting rate causing a significant reduction in solids retention time and a marked change in the nature of the mixed liquor solids, which led to a loss of nitrification. Nitrogen removal was reduced to 58 percent during the last month of study because of these supernatant returns.

6. Sludge settling rates measured during the study ranged from 0.46 to 1.04 m/hr in summer and from 0.18 to 0.69 m/hr in winter. When compared to both conventional and extended aeration operation which preceded the study, no differences in settleability were noted.

7. Although some separation of liquid from solids took place near the surface of the intermittently aerated compartments during the aerator off cycle, the shortness of the off cycle (30 minutes) and the number of cycles occurring provided ample opportunity for denitrification. It is possible, however, that the lack of mixing of organics entering the tank during the off cycle was a limiting factor in achieving a higher degree of denitrification.

8. The amount of oxygen, and thus the energy input, required to operate the process was significantly less than the theoretical amount required for single-stage nitrification without denitrification. This is due to the fact that, under anoxic conditions, the oxygen that was previously supplied to form nitrates is used during denitrification to oxidize a substantial portion of the influent carbon. Thus, during denitrification, nitrate is the final electron acceptor rather than oxygen supplied by aeration equipment.

9. During the aerobic cycle, dissolved oxygen levels of about 0.7 to 1.0 mg/l appeared most compatible with process objectives. Lower concentrations appeared to inhibit nitrification, while higher concentrations delayed the onset of denitrification when the aerator was turned off.

10. At no time was there any indication of rising solids due to denitrification in the final settling tanks. This may be attributed to the use of continuous aeration immediately prior to final settling which provided the following benefits: (1) oxidation of residual carbonaceous material to minimize available carbon and (2) increased dissolved oxygen levels to avoid anoxic conditions in the settling tanks.

11. Nitrification and denitrification kinetic rate test results correlated reasonably well with published data from other studies. However, additional research is necessary to perfect test procedures and to establish design procedures based upon the use of kinetic rates.

12. The process was responsive and straightforward to operate. Once nitrification was established, cycling of the aerators provided immediate denitrification indicating that denitrifying organisms are present in substantial numbers even when only carbonaceous oxidation and nitrification are employed.

13. In addition to an understanding of the fundamentals of activated sludge, the operator must also be trained in the basic biology of nitrification and denitrification to achieve effective performance under all conditions.

14. Removal of alkalinity correlated sufficiently well with the degree of nitrification to enable the use of alkalinity measurements as an operating tool to monitor the nitrification portion of the process. However, alkalinity differences with and without denitrification were slight, and thus alkalinity could not be used effectively to monitor denitrification.

15. Experiments were conducted to evaluate the use of specific ion probes for process monitoring of nitrification and denitrification. The ammonia-nitrogen probe results correlated well with wet chemistry analyses indicating that the probe is an excellent tool for monitoring nitrification. The nitrite probe and cadmium reduction column technique for nitrate measurement could not be fully evaluated due to difficulties with the reduction column. More test work is needed to establish this technique.

16. A number of special design considerations were identified during the study. These have been presented in a separate section of the report.

17. The results of this study, along with recent research by others, indicate that single-stage nitrification-denitrification is capable of 80 to 90 percent nitrogen removal at significantly lower capital and operating costs compared to other nitrogen removal processes. These potential savings warrant further research to expand the applicability of the process concepts in both existing and new plants. Additional research subjects identified during the studies reported herein have been summarized in a special section of this report.

SECTION 3

BACKGROUND

Considerable research has been reported on biological processes for nitrification and denitrification to provide nitrified effluents or nitrogen removal from wastewater (10, 11). Three basic classes of organisms are required to achieve the removal of carbonaceous and nitrogenous materials in a suspended growth biological reactor. Aerobic heterotrophs provide carbonaceous removal by microbial assimilation and oxidation. Aerobic autotrophs, collectively known as nitrifiers, provide oxidation of nitrogen in a two-step microbial reaction; first, ammonia is converted to nitrite by Nitrosomonas; and then, nitrite is converted to nitrate by Nitrobacter. Facultative heterotrophs provide denitrification by nitrate respiration, i.e., the microbial reduction of nitrate to nitrogen gas. The nitrate radical acts as the electron acceptor and organic carbon sources serve as electron donors under anaerobic or anoxic conditions. Facultative organisms are also capable of oxidizing carbonaceous material under aerobic conditions.

Optimum environmental and operating conditions for each of these classes of bacteria differ from one another. Nitrifying bacteria have more specific environmental requirements than the heterotrophic bacteria responsible for carbon removal. The nitrification rate in the activated sludge process reportedly (3) reaches a maximum at dissolved oxygen (DO) concentrations of approximately 2 mg/l or above, and decreases to zero as the DO concentration decreases to zero. Although some denitrification can occur in aerobic systems, maximum denitrification rates occur at DO concentrations near zero, when ample organic carbon is available. Because of the varying conditions best suited for each type of bacteria, two-stage and three-stage systems for nitrification-denitrification with supplemental carbon addition received the most attention initially. However, because multi-stage systems have high capital and operating costs, the search for more economical alternates has intensified.

The most significant and recent single-stage nitrification-denitrification studies were conducted at the USEPA Blue Plains Pilot Plant in Washington, D.C. Bishop, et al., (3) achieved 75 to 84 percent nitrogen removal from primary wastewaters in a single-stage activated sludge process without the use of supplemental organic carbon. Aeration cycles of 30 minutes were alternately applied to each pass of a two-pass biological reactor to achieve aerobic-anoxic conditions. The data suggested that increases in the COD/TKN ratio above 10 would further increase nitrogen removal. Reducing the COD/TKN ratio to 7.5 decreased nitrogen removal to 67 percent. Laboratory kinetic studies indicated that the denitrification kinetic rate controlled the reactor design. Further studies were conducted

by Heidman, et al., (4) at the Blue Plains Pilot Plant to establish an optimum set of operational conditions for a single-stage nitrification-denitrification activated sludge system. Successful operation of the system was attributed to the long solids retention time (SRT) which establishes a relatively high and constant ratio of nitrifiers to heterotrophs. In contrast to the system used in the initial study which employed intermittent air pulsation throughout the reactor, the latter study employed a plug flow biological reactor in which the head end was aerated, the middle section was stirred, and the end section was aerated. Preliminary cost comparisons indicated that this system can achieve comparable process performance results to the three-stage system at a significant reduction in cost.

SECTION 4

DESCRIPTION OF TREATMENT FACILITIES

Owego Water Pollution Control Plant No. 2 (Figure 1) is located in the Hamlet of Apalachin, Town of Owego, in the southern portion of Central New York State near Binghamton. The Town of Owego and the treatment plant itself are located on the banks of the Susquehanna River. The plant is designed for a year 1990 flow of 7,600 cu m/day (2.0 mgd) and was placed in operation in 1971.

Flexibility was provided in the design to allow for operation during the initial low flow years as an extended aeration plant and to allow operation in the conventional activated sludge or contact stabilization mode as wastewater flows increase over the design life of the plant. During the year previous to start-up of the single-stage nitrification-denitrification study, the plant had been operated as a low-loaded conventional activated sludge treatment plant. Currently, plant flow is approximately 1,900 cu m/day (0.5 mgd). A schematic flow diagram of the treatment facilities is shown in figure 2. A summary of key plant components is presented in Table 2.

The wastewater at Owego is typically domestic in character. While operating in the conventional activated sludge mode prior to initiation of the study, the plant had been achieving BOD_5 and suspended solids (SS) removals above 90 percent.

FIGURE 1. OWEGO WATER POLLUTION CONTROL PLANT NO. 2

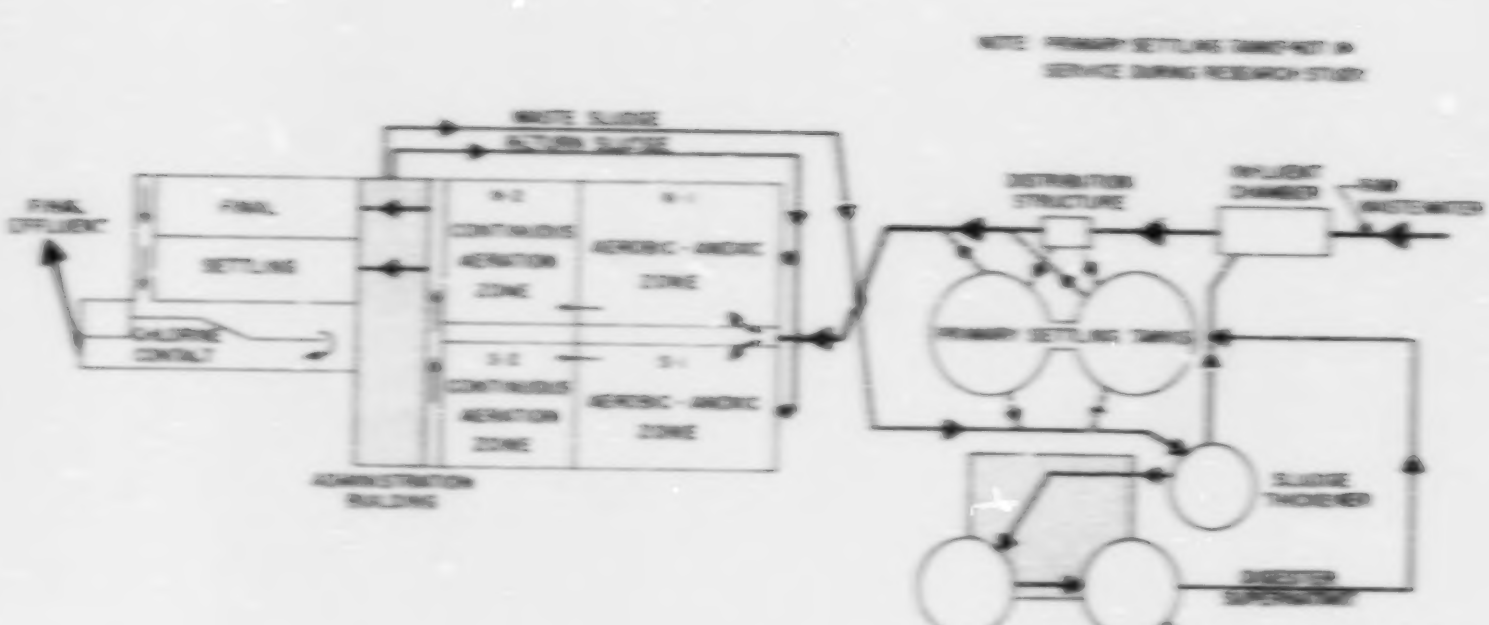


FIGURE 2. SCHEMATIC FLOW DIAGRAM SINGLE-STAGE NITRIFICATION-DENITRIFICATION, OMEGA WATER POLLUTION CONTROL PLANT NO. 2

TABLE 2. MAJOR PLANT COMPONENTS

Component	SIU	English
Bar Rack, Hand Cleaned		
No. of Units	1	1
Units Capacity	19,000 cu m/day	5 mgd
Comminutor		
No. of Units	1	1
Units Capacity	19,000 cu m/day	5 mgd
Grit Separators		
Cyclone Degritter, Primary Sludge	1	1
Cyclone Size	0.3 m	12 in.
Flow Meters		
Parshall Flume	0.23 m	9 in.
Flow Range	0-19,000 cu m/day	0-5 mgd
Flow Tube (Return Sludge)	1	1
Flow (Waste Sludge)	1	1
Flow Tube (Thickened Sludge)	1	1
Primary Settling Tank:		
No. of Units	2	2
Total Surface Area	230 sq m	2,480 sq ft
Diameter	17 m	60 ft
Average Depth	2.7 m	9 ft
Aeration Tanks		
No. of Tanks	2	2
No. of Compartments Per Tank	2	2
Volume of Compartments		
First Compartment (A-1 and B-1)	1,190 cu m	42,000 cu ft
Second Compartment (A-2 and B-2)	780 cu m	27,000 cu ft
Depth	3.7 m	12 ft
No. of Mechanical Aerators Per Compartment	1	1
Aerator Horsepower	11 kw	15 hp
Return Sludge Rate	1,900-5,700 cu m/day	0.5-1.5 mgd
Final Settling Tanks		
No. of Rectangular Units	2	2
Length	20 m	65 ft
Width	4.4 m	14.5 ft
Average Depth	2.6 m	8.5 ft
Surface Area	240 sq m	2,600 sq ft
Total Volume	630 cu m	167,000 gal
Chlorine Contact Tanks		
No. of Rectangular Units	1	1
Length	17 m	60 ft
Width	4 m	13 ft
Depth	1.8 m	6 ft
Total Volume	200 cu m	52,000 gal
Sludge Digestion Tanks		
No. of Units	2	2
Diameter	12 m	40 ft
Sidewall Operating Depth	9 m	30 ft
Sludge Thickening Tank		
No. of Units	1	1
Diameter	7.3 m	24 ft
Sidewater Depth	2.4 m	8 ft
Sludge Disposal		
Tank Truck	1	1
Tank Capacity	7.6 cu m	2,000 gal
Emergency Open Sludge Drying Areas	1	1
Total Area	4,050 sq m	1 acre

SECTION 5

PROCESS MODIFICATIONS AND MONITORING

EXPERIMENTAL PLAN

To achieve single-stage nitrification-denitrification in an activated sludge system utilizing wastewater organics as the carbon source for denitrification, the plan was to provide alternating aerobic-anoxic conditions within the reactor and to provide sufficient SRT to obtain a stable nitrifying population within the mixed liquor.

To provide alternating aerobic-anoxic conditions, the mechanical aerators in Compartments N-1 and S-1 (see Figure 2) were each to be cycled by installing automatic timers. No additional mixing was to be provided during the anoxic stage when the aerator was off; however, it was anticipated that the residual rolling action caused by mechanical aeration would keep the solids suspended to a reasonable extent during the off cycle. In addition, by keeping the anoxic cycle relatively short, liquid-solids separation would be minimized. Mechanical aerators in Compartments N-2 and S-2 were to provide continuous aeration to oxidize residual ammonia (NH_4-N) and carbonaceous material and to prevent sludge bulking in the secondary clarifiers caused by denitrification of nitrified mixed liquor.

To increase the concentration of solids, and thereby increase the SRT, it was anticipated that the sludge wasting rate would have to be significantly reduced. Mixed liquor was settled in two rectangular final settling tanks with middle- and front-end hoppers. The return sludge piping layout was such that the same pump was used to return sludge from both sets of hoppers to the head of the reactor.

The study was divided into two phases: warm weather operation and cold weather operation. Shorter hydraulic retention times (HRT's) were investigated during each phase of the study once the process had been established at longer HRT's, assuming that sufficient SRT was provided throughout. Operation in the winter was of particular interest because cold weather was considered to be the critical controlling environmental factor of the study.

OPERATIONAL PROGRAMS

In preparation for the change to the single-stage nitrification-denitrification process, the mixed liquor suspended solids (MLSS) concentration was increased. Starting in November 1974 sludge wasting was

discontinued. The MLSS concentration increased from 1,000 mg/l in mid-November to 3,600 mg/l in early January 1975. On January 7 both aeration tanks were put into service to fully establish the extended aeration process. The HRT in the aeration tanks was increased from approximately 12 hours to 24 hours. The process of building up the MLSS inventory was continued.

The major operating modification necessary to initiate the study was the bypassing of raw wastewater directly into the aeration tanks, rather than through the primary settling tanks as normally done. Beginning January 27, the influent was piped directly to the aeration tanks to enhance the carbon/nitrogen ratio entering the aeration tanks. This was done in line with the finding at the Blue Plains pilot single-stage system that a relatively high BOD/TKN ratio is needed for effective denitrification.

One of the most important features of process development and operation was the creation of alternating periods of aerobic and anoxic conditions. Computations indicated that the aerators installed at Owego could supply the oxygen required for carbonaceous oxidation and for nitrification, even when operating on a 50 percent on-off cycle. This would then allow adequate time for denitrification to occur during the off cycle. As the aerators are of the variable submergence type, the oxygen required could be provided in a short aerobic cycle at high submergence, or during a long aerobic cycle at low submergence. This would allow the duration of the aerobic and anoxic cycles to be balanced in accordance with nitrification and denitrification kinetic rates.

All major interior and exterior equipment items had been well maintained and were in excellent operational condition at the time of start-up for the study. The only operational difference noted as a result of the pre-study modifications was a moderate increase of scum in the final tanks, but the scum baffle effectively prevented the scum from entering the final weir box.

Prior to initiation of cycling the aerators, the following program was outlined for the start-up period beginning March 18:

a. Continue existing operation for background base line data.

b. Collect 6-hour composites manually until automatic samplers are operational. Sample raw wastewater (downstream of supernatant return) and unchlorinated effluent.

c. Check out plant laboratory and independent commercial laboratory with reference samples.

d. Modify recycle rate to optimize clarifier performance and reduce rate if possible whenever 30-minute return sludge settling sample shows excess supernatant.

e. Waste activated sludge to control MLSS at 3,000 mg/l.

f. Characterize settling velocity of MLSS in each aerator.

g. Determine deoxygenation rate and oxygenation rate with manual control of surface aerators.

h. Inspect and make operational the movable weirs on aeration tanks so oxygen transfer capacity of surface aerators can be varied.

i. Characterize the quality of digester supernatant.

j. Sample mixed liquor between large and small aeration compartments periodically.

In addition, the following equipment modifications were made:

a. Automatic timer installation on motors of mechanical aerators.

b. Install automatic sampler housings.

c. Repair aeration tank weir drives.

d. Install manual bar screen at aerator influent channel to minimize rag accumulations on aerator blades.

e. Install flow splitter at aerator influent.

f. Balance flows to final tanks.

g. Repair of solenoids on return sludge suction valves.

h. Order and install laboratory equipment and minor electrical and physical equipment.

Once all of the above tasks had been completed, Phase I (warm weather operation) of the study was ready to begin. On May 5, the timers on the aerators in Compartments 5-1 and 6-1 were pulsed on a 30-minute staggered on-off cycle. The aerators in Compartments 5-2 and 6-2 were set to remain running continuously. Figure 3 shows Compartment 5-1 in its aerobic cycle and Compartment 6-1 in its anoxic cycle. 5-2 can be seen in the foreground. This initiated the denitrification phase of the single-stage nitrification-denitrification process utilizing wastewater organics as the carbon source for denitrification. The process was operated in this manner for the remainder of the study period, varying only the aeration tankage in service and the submergence of aerator blades. No attempt was made to fine tune the process by optimizing the aerator on-off cycles. Sludge disposal was as normally practiced, employing two-stage digestion of thickened sludge followed by ultimate disposal to the land.

The critical phase of the project, Phase II, took place during the late winter and spring of 1976 when cold temperature performance was studied.

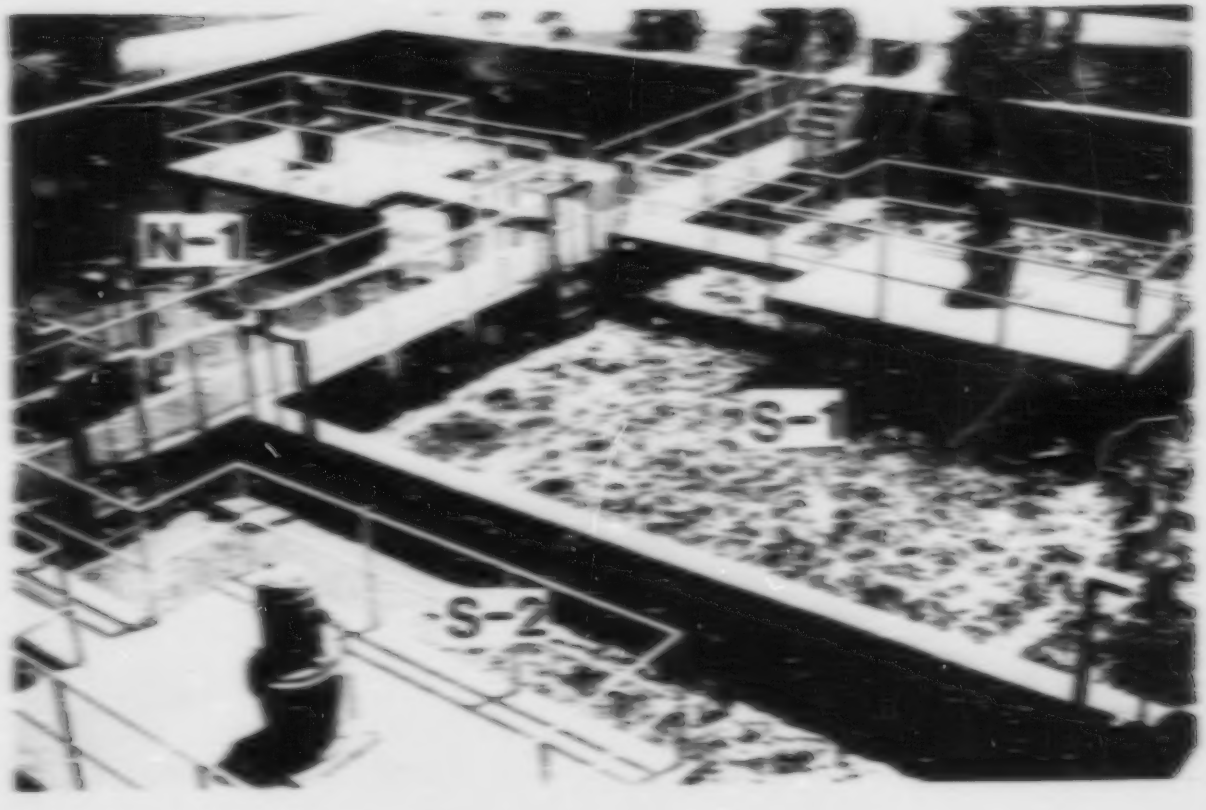


FIGURE 1. ALTERNATING AEROBIC-ANOXIC CYCLES IN COMPARTMENTS N-1 AND S-1

The sequence of events for the entire pre-study and study periods is shown in Table 3, which can be conveniently subdivided into the following:

- Pre-Study Period - Process modifications beginning in November 1974.

- Phase I Start-Up (March 18-May 4) - Final preparations for warm weather operation (11°-22°C) including equipment modifications and checkout, initiation of sampling program and laboratory checkout.

- Phase IA (May 5-July 16) - First portion of the warm weather phase using all aeration tank capacity.

- Phase IB (July 17-September 8) - Second portion of the warm weather phase at half the aeration tank capacity to explore the effects of reduced tankage on process performance.

- Standby Period (September 9-February 2) - Study was temporarily discontinued, to be reinstated in February to evaluate plant performance during cold weather. In the interim, a 9- to 11-hour aeration period with on-off aerator cycling was maintained. Process monitoring and analyses were discontinued and intermittent checks were made to ensure that both nitrification and denitrification were occurring.

- Phase II Start-Up (February 3-March 9) - Initiation of cold weather operation (8°-13°C) phase of the study.

- Phase IIA (March 10-April 30) - First portion of the cold weather phase using all aeration tank capacity.

- Phase IIB (May 1-May 28) - Second portion of the cold weather phase using half the aeration tank capacity to explore the effects of reduced tankage on process performance.

SAMPLING AND ANALYTICAL PROCEDURES

Sampling and Storage

The gathering of data on a 5-day basis for the single-stage nitrification-denitrification study began in late March during the start-up period. Much of the analytical work was performed by the treatment plant laboratory. COD, nitrogen, phosphorus, and certain other special analyses were performed by a commercial testing laboratory. During the start-up period, plant laboratory personnel performed and familiarized themselves with the additional analyses required for the study. These were checked by analysis of split samples by the commercial testing laboratory. Log sheets for analytical and operating data and time and expenses related to the study were developed. During the first four weeks of data gathering, a Technicon Auto-Analyzer was used for COD and nitrogen analyses. Suspicious results, especially for organic nitrogen, necessitated a change to manual analytical techniques. Analytical procedures were checked on unknown samples provided by the Environmental Protection Agency.

TABLE 3. SEQUENCE OF EVENTS

Pre-Study

November 1974	◦ Sludge wasting discontinued
January 7, 1975	◦ Second aeration tank put in service
January 27, 1975	◦ Primary clarifiers taken off line
March 1, 1975	◦ Grant Funded

Phase I Start-Up

March 10, 1975	◦ Initiation of operational and equipment modifications
March 24, 1975	◦ Nitrogen series analysis started
April 10, 1975	◦ Changed labs (Technicon Auto-Analyzer to wet chemistry)

Phase IA

May 5, 1975	◦ Air pulsed on 30-minute cycle
May 28, 1975	◦ Aerator blade submergence increased to 6 inches
June 13, 1975	◦ Aerator blade submergence increased to 7 inches

Phase IB

July 17, 1975	◦ North aeration tank (N-1 and N-2) taken out of service
August 1975	◦ Primary digester malfunction--taken out of service
September 8, 1975	◦ Discontinued study until cold weather period
October 1975 thru January 1976	◦ Monitored on random basis
January 28, 1976	◦ Hydraulic washout of solids

Phase II Start-Up

February 3, 1976	◦ Aerator blade submergence decreased to 5 inches
February 12, 1976	◦ Measures taken to reestablish process; north aeration tank put in service; all aerators placed in continuous operation

Phase IIA

March 10, 1976	◦ Pulsing started; resumed monitoring program
March 1976	◦ Began cleaning out primary digester

Phase IIB

May 1, 1976	◦ North aeration tank (N-1 and N-2) taken out of service
May 28, 1976	◦ Study terminated

The following analyses were performed by the commercial testing laboratory and plant laboratory during the study period.

Five-Day Basis -

Influent and Effluent: BOD_5, COD, SS, Org-N, NH_4-N, NO_2-N, NO_3-N, Alkalinity (Composite Samples)
Temperature, pH, Settleable Solids (Grab Samples)

Mixed Liquor: MLSS, pH, Settleable Solids, SVI (Grab Samples)

Return Sludge: Settleable Solids, Total Solids (Grab Samples)

Random Basis -

Influent and Effluent: VSS, Total-P (Grab Samples)

Mixed Liquor: MLVSS, COD, DO, Temperature (Grab Samples)

Mixed Liquor Supernatant: BOD_5, COD, SS, VSS, Org-N, NH_4-N, NO_2-N, NO_3-N (Grab Samples)

Return Sludge: COD, SS, VSS, Org-N, NH_4-N, NO_2-N, NO_3-N (Grab Samples)

Secondary Digester Supernatant: BOD_5, COD, SS, Org-N, NH_4-N, NO_2-N, NO_3-N, Total-P, Alkalinity (Grab Samples)

Primary and Secondary Digester Sludge: pH, Total Solids, Total Volatile Solids, Alkalinity (Grab Samples)

Because of problems in obtaining delivery of two automatic samplers and operating difficulties experienced with one or both of the samplers, continuous 24-hour sampling could not always be obtained. Laboratory results of 24-hour automatically composited samples were examined against results for 6- and 8-hour manually composited samples. COD, BOD_5, SS, and N-series results were compared in periods when both sampling methods were utilized, and no discernible differences were found. Samples were not taken on Saturdays, Sundays, or holidays. Influent samples were collected at the entrance to the aeration tanks to include the contributions of digester supernatant and septic wastes. Effluent samples were collected at the effluent weir of the final settling tanks prior to chlorination.

Tests of acidified versus non-acidified samples were conducted the latter part of May and the middle of June 1975 to determine the more effective method in preserving samples to be sent to the commercial laboratory. After one week of refrigeration, the samples were analyzed for NH_4-N and nitrate (NO_3-N) and compared to the fresh sample that had been analyzed shortly after being collected. The values for the sample with acidification were closer to those of the fresh sample. Thereafter all influent and effluent samples to be sent to the commercial laboratory for COD and nitrogen analyses were acidified with concentrated sulfuric acid to pH 2.0 and stored

at 4°C until analyzed. All samples to be analyzed by plant personnel were refrigerated only and determinations were performed within 24 to 48 hours of collection.

A specific ion meter, Orion Research Ionalyzer Model 407A, was obtained to assist plant operators in evaluating process performance. The analyzer was evaluated specifically for two reasons:

1. To compare the accuracy of the analyzer to wet chemistry techniques for NH_4-N and NO_3-N measurements.

2. To evaluate its use as a plant process control and monitoring tool.

Analytical Techniques

Oswego Water Pollution Control Plant No. 2 Laboratory--
All analytical procedures were in accordance with the procedures authorized in Standard Methods for the Examination of Water and Wastewater (1), 13th edition, unless otherwise specified.

pH--The glass electrode method was used as outlined in Standard Methods, pages 276-281. The plant used a Corning Model No. 7 pH meter.

Temperature--Measurements were taken with a mercury-filled thermometer as outlined in Standard Methods, pages 348-349.

Dissolved Oxygen--DO measurements were taken with a Yellow Springs DO meter, Model No. 57. The instrument was calibrated against the modified Winkler method.

Alkalinity--The total alkalinity determinations were performed as outlined in Standard Methods, pages 52-55, using the potentiometric method.

Solids--Sludge Volume Index (SVI)--The SVI's were performed as outlined in Standard Methods, page 561.

Settleable Solids--The settleable solids were determined as outlined in Standard Methods, page 539.

Suspended Solids--The SS content was determined using the method outlined in Standard Methods, pages 537-538.

Total Solids--The total solids content was determined using the procedure outlined in Standard Methods, page 536.

Biochemical Oxygen Demand--The 5-day BOD determinations were made as outlined in Standard Methods, pages 489-494, employing the azide modification of the Winkler test, as described in Standard Methods, pages 477-489.

Commercial Laboratory--

All analytical procedures were in accordance with the procedures outlined in Standard Methods for the Examination of Water and Wastewater (1), 13th edition, or the USEPA's Manual of Methods for Chemical Analysis of Water and Wastes (9), 1974 edition, unless otherwise specified.

Chemical Oxygen Demand--The dichromate reflux method, as presented in Standard Methods, pages 495-499, was the procedure used for all COD determinations with one minor variation. The 30 ml of sulfuric acid reagent were added directly into the Erlenmeyer flask and not through the condenser. Sulfamic acid (0.12 g) was added to every liter of standard 0.25 N potassium dichromate solution. A 20 ml sample or a sample diluted to 20 ml with distilled water was used for analysis.

Nitrogen--Nitrate-Nitrogen--The NO_3-N determinations were made as outlined in the USEPA Manual of Methods, pages 197-200, employing the brucine method.

Nitrite-Nitrogen--The nitrite-nitrogen (NO_2-N) determinations were made as outlined in the USEPA Manual of Methods, pages 215-216.

Ammonia Nitrogen--The NH_4-N concentration was determined using the method for organic nitrogen (Org-N) as described in Standard Methods, pages 246-247, with the elimination of the digestion step. Distillation of the ammonia fraction was accomplished on a Lab-Con-Co. distillation apparatus with final ammonia measurement by titration.

Organic Nitrogen--Org-N concentrations were determined by digestion and distillation of the residue from the NH_4-N determination, as outlined in Standard Methods, pages 246-247.

Biochemical Oxygen Demand--The 5-day BOD determinations were made as outlined in Standard Methods, pages 489-494. An oxygen probe was employed in making initial and final oxygen determinations. It should be noted that DO's were taken on each BOD bottle no matter what the initial volumes of samples were. The DO meter (Yellow Springs Instrument, Model No. 57) was standardized against the azide modification of the Winkler test.

Solids--Suspended Solids--The SS content was determined using Procedure 224C as outlined in Standard Methods, pages 537-538.

Volatile Suspended Solids--Volatile suspended solids (VSS) were determined by Procedure 224D as outlined in Standard Methods, page 538.

Total Solids--The total solids content was determined using Procedure 224A as outlined in Standard Methods, pages 536-536.

Total Volatile Solids--The total volatile solids were determined by Procedure 224B as outlined in Standard Methods, page 536.

Alkalinity--The total alkalinity determinations were performed as outlined in Standard Methods, pages 52-55, using the potentiometric method.

Specific Ion--An Orion Research Ammonia Electrode (Model No. 95-10) and an Orion Specific Ion Meter (Model No. 407A) were used in a comparison study between wet chemistry and the electrode method.

An Orion Research Nitrite Electrode (Model No. 95-46-02) and an Orion Specific Ion Meter (Model No. 407A) were used in a comparison study between wet chemistry and the electrode method. Samples to be analyzed by the Nitrite Electrode were first passed through a cadmium reduction column to reduce NO_3-N to NO_2-N.

Special Tests

Special tests were conducted periodically to assist in monitoring and evaluating process performance and to help in determining design and operating criteria.

1. DO profiles were performed in aeration tanks using a DO meter and probe 8 to 10 feet below the waterline to determine the rates of oxygenation and deoxygenation during on-off cycling of the mechanical aerators in A-1 and B-1.

2. Batch settling tests were conducted to determine the settling rate of mixed liquor solids. During Phase I a 1-l graduated cylinder was utilized for this purpose; and during Phase II a 10.5-cm (4-1/8-in.) diameter column, 122 cm (48 in.) long was used. Stirring was not provided in either case.

3. Laboratory scale batch nitrification-denitrification kinetic studies were performed to determine the kinetic rate at which each biological reaction occurs. These studies were performed by batch mixing 5 l of return sludge with 5 l of influent, aerating with the laboratory air supply, and extracting samples at 15-minute intervals for a 2-hour period. At the end of 2 hours, aeration was discontinued and 3 l of fresh influent were added to the remaining mixed liquor. The solution was then gently mixed and samples were extracted every 15 minutes for the next hour. The temperature of the mixed liquor was measured throughout the test, but a water bath was not used to maintain a constant temperature. Samples were analyzed for COD and nitrogen constituents. From these data, the kinetic rate constants of nitrification and denitrification were determined.

SECTION 6

PROCESS CONTROL AND PERFORMANCE

GENERAL

The purpose of this section is to describe the operating techniques and controls employed during both major phases of the study and to present the operational loadings and process performance observed. The tables which present these operating and performance data have been included at the end of this section to avoid unnecessary fragmentation of the data and to enable the reader to more readily review the results of the entire study, by referring to Tables 4, 5, 6 and 7.

PHASE I - WARM WEATHER OPERATION

In early May 1975, the installation of the timers for the mechanical aerators was completed. By that time, laboratory sampling and analytical procedures had been checked and plant personnel had been oriented to the additional demands of the study. In addition, essentially complete nitrification had been established.

Laboratory results on influent samples collected during the start-up operations showed a large variation in the influent strength. These variations were attributed to three major factors: (1) the periodic flushing of a siphon under the Susquehanna River, (2) the inflow of digester supernatant when sludge was wasted, and (3) the dumping of septic waste by commercial septic tank pumpers. As such situations are normally uncountered in practice, no attempt was made to shield the process from their effects.

Phase IA - All Aeration Tanks in Service

On May 5, pulsing of the S-1 and N-1 aerators on the 30-minute on-off cycle was started to establish suitable conditions for denitrification. Cycling of the timers reduced the operating DO level in aeration basins N-1 and S-1 from 5 to 1 mg/l. The average DO level for Phase IA in continuously aerated Compartments S-2 and N-2 was approximately 3.6 mg/l. The response of the process to cycling was immediately apparent as the final effluent NO_3-N concentration decreased from 12 mg/l to approximately 5 mg/l as a result of denitrification during anoxic conditions. Effluent quality remained constant and floating scum normally observed in the aeration and final settling tanks disappeared. Towards the latter part of May the residual NH_4-N, and thus, the residual total nitrogen (Total-N) concentration increased. This was attributed to insufficient DO levels (approximately 0.5 mg/l) attained during the aerator on cycle. An increase in wastewater temperature resulted in less oxygen transfer as well as a higher bacterial

metabolism rate. To increase the amount of oxygen supplied, the aerator blade submergence was increased on May 28 by raising the weir levels 2.5 cm (1 in.) for both tanks. Effluent NH_4-N levels returned to levels consistent with previous results. Anticipating the warmer summer temperatures, the submergence of the aerator blades was increased by 5.1 cm (2 in.) on June 13 to further increase the oxygen supplied. During the course of the entire study, DO concentrations were periodically checked (Figure 4) for an entire on-off aerator cycle. Figure 5 is a plot of typical DO concentrations occurring during one complete cycle. This pattern varied depending on temperature, solids inventory, and wastewater characteristics.

Nitrogen removals for May averaged 76.4 percent and for June averaged 80.6 percent. In the last week of June, however, residual NO_3-N levels began to increase. Previous to this, effluent NO_3-N concentrations were approximately 5 mg/l. By July 1, effluent NO_3-N had risen to 11 mg/l and remained at that level or above for the period of July 1-16, indicating that little denitrification was being achieved. Total-N removal for this period decreased to approximately 67 percent.

Because influent wastewater temperatures had risen significantly during June, while maintaining a constant solids inventory, it was believed that the lack of denitrification was being caused by complete oxidation of organic carbon during the aerobic cycle. This in turn reduced the carbon available for denitrification during the anoxic cycle. This condition was intensified by a lower than usual COD/TKN ratio during early July. To prevent the premature consumption of carbon it was decided to reduce the mixed liquor solids inventory within the system. It was possible to accomplish this in one of two ways:

1. By gradual wasting of MLSS to the digesters until denitrification was restored.

2. By removing one aeration tank, and its mixed liquor solids, from service.

A series of calculations was made that indicated that it should be possible to sustain nitrification and denitrification at the same mixed liquor solids concentration with one-half of the aeration tankage. The calculations also indicated that the aerator oxygenation capacity of one tank would be somewhat less than the theoretical amount needed to accomplish carbonaceous and nitrogenous oxidation. However, because much of the oxygen used for nitrification is reused for carbonaceous oxidation during denitrification, it was believed that the aerator oxygenation capacity could be adequate.

Upon review of the factors involved it was decided to remove one-half of the aeration tankage, and its contents, from service. Incidental to the decision was the observation that the mixed liquor solids inventory had been reduced by about 20 percent during late June and early July with no improvement in denitrification. Therefore, on July 16, the north aeration tank (Compartments N-1 and N-2) was isolated from the treatment process. This change constituted the end of Phase IA and the beginning of Phase IB.

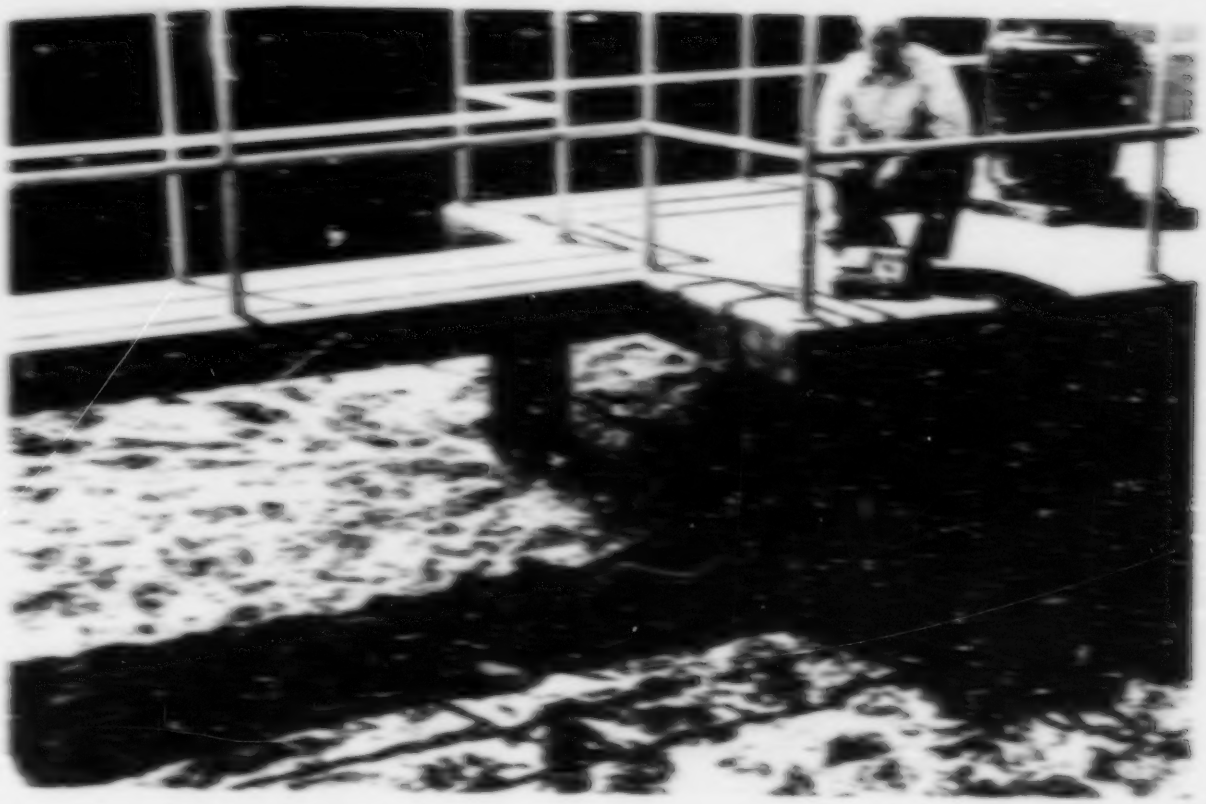


FIGURE 4. [illegible] TEST IN COMPARTMENT 5-1

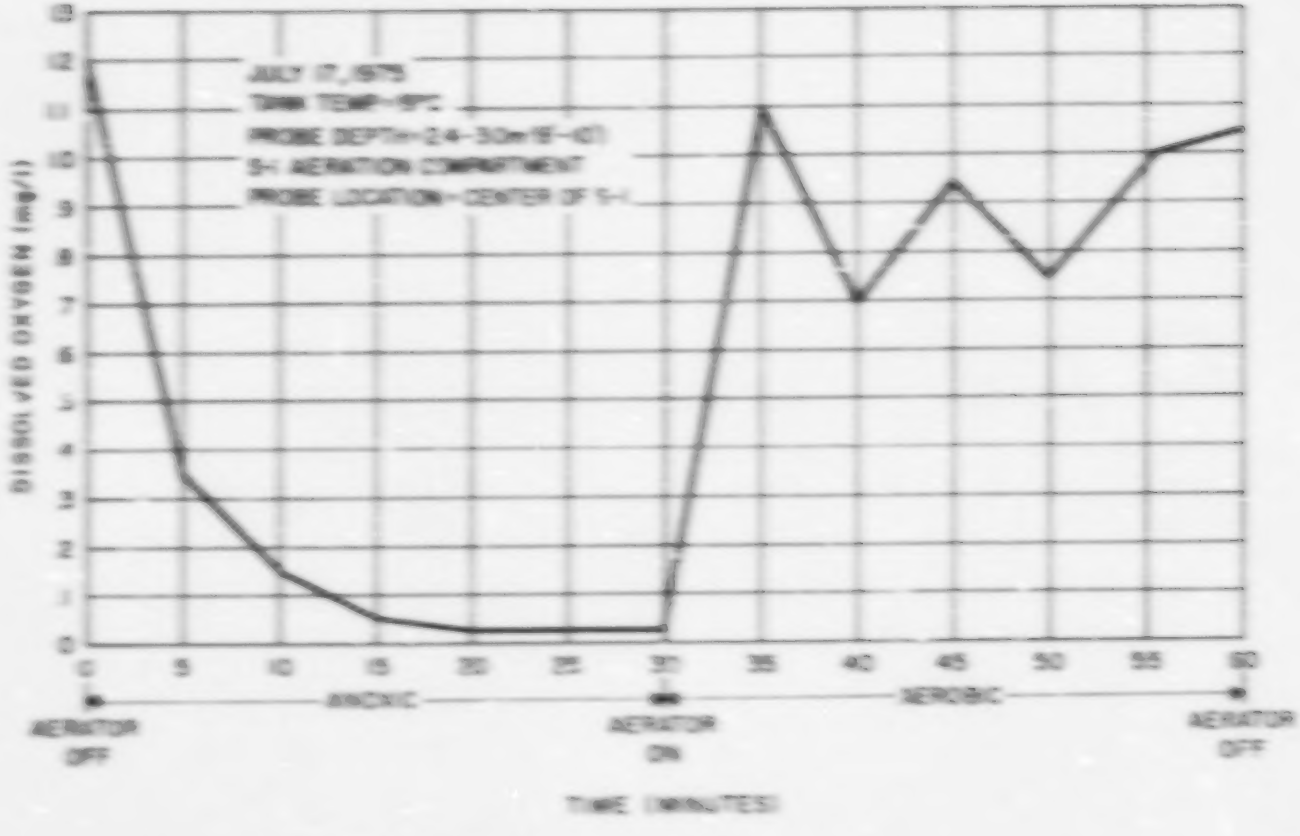


FIGURE 5. TYPICAL AEROBIC - ANOXIC CYCLE

A complete tabulation of the operational loadings and process performance during Phase IA is included in the tables at the end of this section. As may be seen, excellent removals of BOD, COD and SS were consistently achieved under loading conditions typical for an extended aeration system, while simultaneously achieving a high degree of nitrification and nitrogen removal.

Phase IB - One Aeration Tank in Service

By inactivating the north aeration tank and the MLSS contained therein, the HRT was reduced from 28 hours in Phase IA to 14 hours for Phase IB and the operational SRT was reduced from more than 40 days to less than 20 days. The F/M ratio was increased from about 0.06 g BOD_5/day/g MLVSS to about 0.13. An immediate improvement in nitrogen removal took place while BOD, COD, and SS removals remained constant. The operating DO levels for Phase IB generally ranged from 0.8 to 1.0 mg/l in Compartment 5-1 and was approximately 2.2 mg/l in 5-2. Effluent NO_3-N values were immediately reduced from 11-13 mg/l to 1-3 mg/l and remained low for the remainder of Phase IB during which the warmest wastewater temperatures of the study (18° to 22°C) were recorded. A higher degree of denitrification was achieved in Phase IB as effluent NO_3-N concentrations were lower. Total-N removals during this period were consistently around 85 percent and on several days exceeded 90 percent. The results confirmed that the decrease in nitrogen removal in the latter portion of Phase IA was caused by a deficiency of carbon source.

Total-N removal for the first week in September decreased to 77.1 percent due to the combination of lower influent total-N and a slight increase in effluent total-N.

Excellent BOD_5, COD, and SS removals were maintained throughout this phase. BOD_5 and SS residuals were consistently less than 10 mg/l, while COD removals averaged slightly less than 90 percent.

During Phase IB, HRT's in the aeration tanks averaged 13 to 16 hours, and SRT's averaged 13 to 19 days. Wastewater flow rates did not significantly change from Phase IA; therefore, the surface overflow rate (SOR) and HRT in the final settling tanks remained in the same ranges. The BOD_5 loading approximately doubled, and the F/M ratio increased but did not double due to higher MLSS levels. Values of SVI were not quite as high in July and August probably because of the improved sludge settling properties caused by warmer temperatures and the change in mode of operation. Results of 30-minute settleability tests were generally better than those in Phase IA.

In August an operational problem potentially detrimental to the process was created when the emergency overflow on the fixed cover primary digester plugged. Continued waste sludge pumping caused failure of the anchor bolts and brackets which held the cover in place. The tank was removed from service and operation of the secondary digester was modified to allow it to function as a primary digester. A sludge recirculation pump was used to provide mixing within the digester. The pump was turned off to allow liquid-solids separation prior to the introduction or removal of sludge. Digester supernatant from this tank was returned to the influent of the aeration tanks.

Based upon the quantity of sludge wasted immediately prior to the digester cover failure, calculations were made to determine the adequacy of the remaining digester. These indicated that the tank capacity would be adequate, as long as digested sludge was removed regularly to avoid deterioration of supernatant quality. Plans were made to empty and repair the primary digester in the fall of 1975 and to place it in service prior to the cold weather portion of the study which was planned for February, March and April of 1976.

In early September it was concluded that the objectives of the warm weather study had been achieved. On September 8, the study was suspended to be reinitiated in February under cold weather conditions. During the interim period until winter conditions prevailed, the plant was operated to maintain nitrification-denitrification. The south aeration tank continued in operation with pulsed aeration on the 30-minute on-off cycle, while the north aeration tank remained out of operation. MLSS were held in the range of 4,000 to 5,000 mg/l. Daily sampling and monitoring were discontinued except for alkalinity measurements. During the fall and winter, spot nitrogen analyses were made to prove that nitrification and denitrification were maintained. Laboratory results for 2 to 3 samples per month for November and December indicated approximately 68 percent and 78 percent Total-N removal, respectively, while the temperature had decreased to 11°C. Destruction of alkalinity continued to be high. Wastewater flow rates significantly increased during this period reducing the aeration tank HRT to approximately 10 to 11 hours, yet good BOD, COD, SS, and nitrogen removals were still achieved. The plant was operating well, and conditions appeared to be ideal for the anticipated start-up of Phase II at the beginning of February 1976.

Daily wastewater temperatures in January 1976 ranged from 7° to 10°C. Daily alkalinity data indicated that essentially complete nitrification was maintained. Although NO_3-N analyses were not performed, the combination of high alkalinity drop, pulsed air operation, and low temperature conditions inhibiting premature carbon consumption was indicative that denitrification should also be occurring.

Extremely high flows were encountered towards the end of January. Precipitation and thawing snow during unseasonably warm temperatures caused groundwater infiltration and inflow into sewers under construction. The total plant flow increased from 2,200 cu m/day (0.59 mgd) on January 26 to 4,000 cu m/day (1.06 mgd) on January 27 to 5,000 cu m/day (1.31 mgd) on January 28, causing flooding conditions and a hydraulic washout of solids. The MLSS concentration dropped from 4,100 mg/l on January 26 to 1,400 mg/l on January 28. Shortly thereafter, a large decrease in alkalinity destruction occurred, indicating the probable loss of nitrifying bacteria.

PHASE II - COLD WEATHER OPERATION

Start-Up

Phase II start-up was initiated February 3, 1976, with full resumption of the daily monitoring program for nitrification-denitrification with one

aeration tank in service. The planned work to repair the primary digester had not been done; therefore, the plant continued to operate with a single digester. Although the mixed liquor solids level had increased substantially since the washout, analyses for the period of February 3-11 confirmed that nitrification had been lost. Good removals of COD, BOD, and SS were obtained during this period, indicating that the microorganism population for carbonaceous oxidation had been quickly reestablished. However, the influent NH_4-N concentration was 18.5 mg/l, and the effluent NH_4-N concentration was 15.7 mg/l, while total-N removal was only 24 percent. The SRT was estimated to be 10 days during the first two weeks of February, which may not have been sufficient for the nitrifiers to reestablish themselves at the lower temperature. Flows had stabilized, and the aerator HRT was 10.2 hours.

During this period, plant records indicated for the first time evidence of a problem in digester operation. On February 9-11, heavy supernatant returns were observed caused by insufficient winter withdrawals of digested sludge from the one operating digester. Daily composite sampling was discontinued on February 12, until nitrification was restored.

The following procedures were initiated on February 12 to restore nitrification:

1. To maximize SRT, the north aeration tank was returned to service and sludge wasting was discontinued.

2. To assess the degree of nitrification, alkalinity drop from influent to effluent was closely monitored.

3. To further enhance nitrification, all mechanical aerators were placed in continuous operation and the aeration tank effluent weirs were adjusted to provide an operating DO concentration of 2 to 4 mg/l.

By the first week in March, the MLSS in both tanks exceeded 3,000 mg/l and the alkalinity measurements indicated that nitrification had been restored. At this time, the mechanical aerators in Compartments N-1 and S-1 were returned to timer control on the 30 minutes on, 30 minutes off cycle.

Phase IIA - All Aeration Tanks in Service

On March 10, daily composite sampling was resumed to evaluate the first portion of cold weather operation, i.e., extended aeration operation with both aeration tanks in service and wastewater temperatures in the 8° to 10°C range. Laboratory results indicated that the nitrifying and denitrifying bacterial populations had been reestablished, as essentially complete nitrification and 77 to 79 percent total-N removal were achieved. Total-N removal efficiencies in March and April were approximately equal to those achieved during Phase IA when the plant operated under similar process loading conditions but at warmer wastewater temperatures. Higher flow rates in Phase IIA resulted in slightly lower HRT's, but no detrimental effect on the process was apparent. The operating DO level in Compartments S-1 and N-1 ranged from 0.7 to 1.0 mg/l. DO readings were not recorded in

5-2 or N-2 in Phase IIA. Excellent BOD_5, COD and SS removals were maintained. Floating solids were observed in the final settling tank, but effluent quality was not impaired.

During March the F/M ratio and SRT were maintained at about the same levels as for Phase IA with MLSS concentrations approaching 4,000 mg/l. In April, MLSS concentrations were intentionally reduced to about 3,000 mg/l to assess operation under somewhat higher F/M ratios. A corresponding reduction in SRT from 32 to 20 days was noted. This reduction in SRT was greater than had been anticipated, probably due to increasing amounts of digested solids being returned in the digester supernatant which in turn necessitated increased wasting to maintain a relatively constant MLSS concentration. In March, plant personnel began to clean out the primary digester which had been idle for several months. Sludge from the digester was trucked away to land disposal areas. Because only one truck and limited manpower were available for this maintenance operation, less digested sludge from the one functional digester was removed as previous to Phase IIA. The net effect was a buildup of solids, inadequate liquid-solids separation, and an increase in supernatant strength. In general, this accounted for the higher sludge wasting rate and lower SRT observed in Phase IIA as compared to that during Phase IA.

Nitrogen removals in April were erratic compared to other periods. During the week of April 11, extremely high nitrogen removals in excess of 90 percent were achieved, while the following week only 63 percent Total-N was removed. Although essentially complete nitrification was achieved throughout April, effluent NO_3-N concentrations ranged from traces to 20 mg/l and tended to increase towards the latter part of the month. At that time, it was thought that the increase in effluent NO_3-N was probably the result of a deficiency in wastewater organics for use as a carbon source during the denitrification step, as had occurred in early July in Phase IA when the temperature increased and the COD/TKN ratio unaccountably decreased.

As had been done in Phase IA, the north aeration tank was removed from service in an attempt to improve Total-N removal and to study the process at reduced retention times under cold weather conditions. By reducing the solids inventory, it was anticipated that sufficient wastewater organics would remain unoxidized to be used as a carbon source during denitrification.

Phase IIB - One Aeration Tank in Service

Utilizing one aeration tank, the second portion of the cold weather phase was conducted during the month of May with wastewater temperatures in the range of 11° to 13°C. Operation of the plant was similar to that during Phase IB with a few noticeable differences. These included: (1) lower influent wastewater temperatures; (2) higher flow rates, giving lower retention times in the aeration and final settling tanks, and higher surface overflow rates in the final settling tanks; (3) slightly lower MLSS levels and correspondingly higher F/M ratios and lower SRT's; (4) stronger supernatant returns resulting from the loss of the primary digester and its subsequent cleaning, causing an inability to remove digested sludge from the secondary digester because of a shortage of vehicles and manpower.

Sludge production during this period was higher than Phase IIA, as would be expected at an increased F/M ratio, but was also significantly higher than sludge production in Phase IB. This was primarily a reflection of solids contributions from the stronger digester supernatant returns.

The SVI's were high in the first part of May and typical of previous plant experience at lower temperatures. Lower SVI's that occurred in late May were the result of a change in sludge settling characteristics caused by inert solids returned in digester supernatant.

Excellent BOD_5, COD, and SS removals were maintained at first in Phase IIB. In the final portion, May 10-28, good removals were obtained; but the treatment efficiency for all these constituents decreased. A similar pattern was observed in nitrogen removals, but the decrease in efficiency from May 10 to 28 was even more noticeable and was due primarily to deteriorating nitrification caused by markedly shortened SRT's resulting from excessive returns of digester supernatant solids. Visible evidence of these effects was provided by the jet black nature of the MLSS. Figure 6 is a picture of influent wastewater samples before and after the point of digester supernatant return. Figure 7 is a picture of the same samples after 30 minutes of settling. The large mass of dark settleable solids returned in digester supernatant is readily apparent. The data suggested that denitrification improved with the reduction to one aeration tank, but before sufficient data could be gathered, the nitrification process had started to fail. By the last week in May, effluent NH_4-N levels had increased to about 15 mg/l and total-N removals had decreased to about 50 percent.

Because of the loss of nitrification and the fact that completion of the primary digester cleaning and repair was not anticipated to be completed for several months more, further testing and process evaluation were terminated. Although difficult to accurately determine, it appeared that a certain degree of denitrification was being achieved up to the time that monitoring was discontinued.

Another operational problem experienced in Phase IIB was the extremely wide daily variations in MLSS. These wide variations were the direct result of the sludge return piping layout. Front-end and midpoint sludge hoppers in the final settling tanks are joined in the same suction line for the return sludge pumps rather than separate lines with separate pumps. Malfunctions in the solenoid valve system used to provide individual, timed withdrawals from each hopper resulted in sludge being drawn from both sets of hoppers. When uneven resistance was encountered, the pump drew the more dilute sludge and, at times, returned essentially only effluent to the aeration tanks. At other times, very heavy sludges were returned from either hopper. This uneven return sludge pumping was probably the main cause for the wide daily variation of MLSS in the aeration tank and may have adversely affected process performance. Although the same piping arrangement was used in Phases IA, IB, and IIA, the same problem was not observed because the sludges for those phases were not as compactible due to the absence of large quantities of anaerobically digested solids.

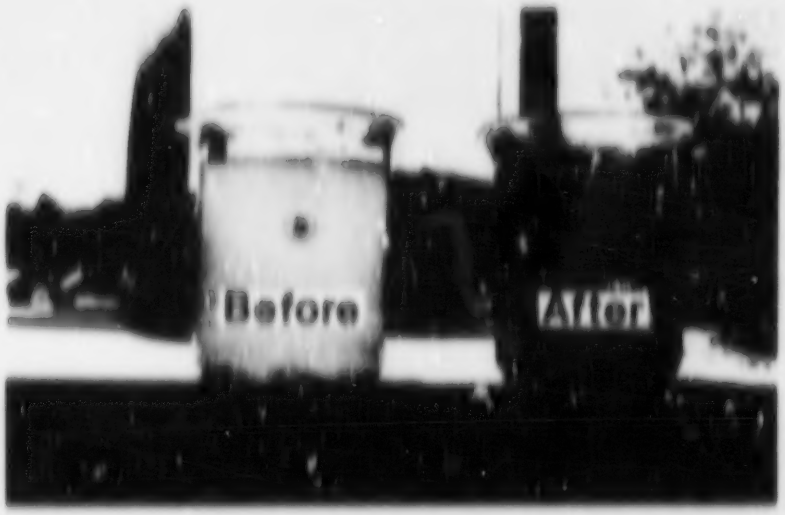


FIGURE 6. INFLUENT WASTEWATER SAMPLES BEFORE AND AFTER DIGESTER SUPERNATANT RETURN POINT

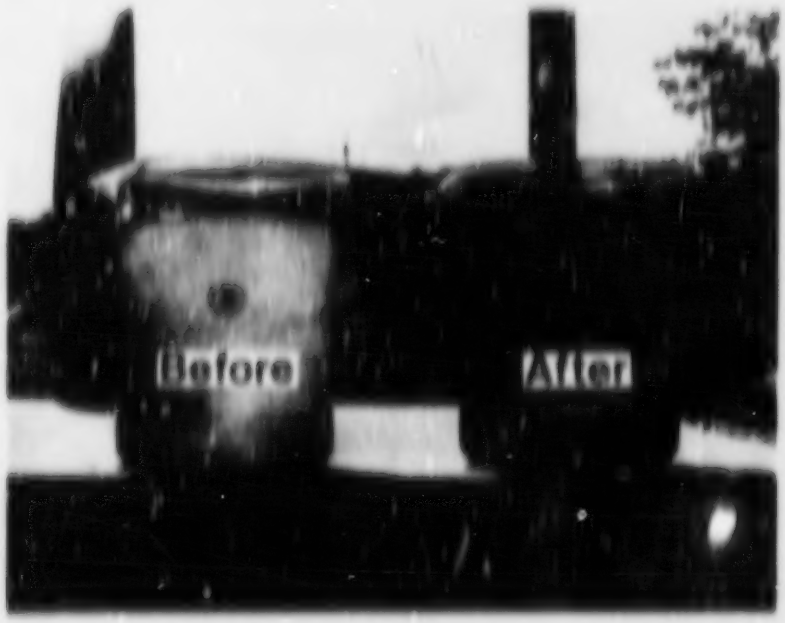


FIGURE 7. SAMPLES IN FIGURE 6 AFTER 30-MINUTE SETTLING

TABLE 4. PROCESS LOADING CHARACTERISTICS

Time Period	Wastewater Flow, mgd Avg.	Wastewater Flow, mgd Range	Wastewater Flow, cu m/day Avg.	Wastewater Flow, cu m/day Range	Aeration Tank BOD Loading, lbs/day/1,000 cu ft	Aeration Tank BOD Loading, kg/day/cu m	Aeration Tank HRT[1,2], hours	Final Settling Tank SOR, gpd/sq ft	Final Settling Tank SOR, cu m/day/sq m	Final Settling Tank HLR, hours	Final Settling Tank SS Loading, lbs/day/sq ft	Final Settling Tank SS Loading, kg/day/sq m
1977												
PHASE IIA-												
May 5-31	0.462	0.33-0.64	1,836	668-2,438	11.9	191	25.7	183	7.5	7.4	5.1	61.7
June	0.498	0.39-0.84	1,730	1,449-2,420	16.1	382	27.3	172	7.0	8.3	4.7	75.3
July 1-19	0.379	0.33-0.44	1,430	1,218-1,678	7.5	125	32.8	140	5.9	32.8	3.2	51.3
PHASE IB -												
July 27-31	0.395	0.39-0.47	1,480	1,369-1,780	10.7	173	25.9	140	6.0	8.7	4.0	64.1
Aug.	0.425	0.33-0.62	1,610	1,259-2,350	20.4	327	14.3	165	6.7	8.7	5.6	97.7
Sept. 1-8	0.460	0.37-0.53	1,730	1,400-2,000	15.1	240	11.4	175	7.1	8.2	5.0	80.9
1978												
PHASE IIA -												
Mar 10-31	0.609	0.59-1.00	2,305	1,749-3,790	13.4	215	10.8	230	9.7	6.0	7.7	123.3
Apr.	0.529	0.33-0.80	1,999	1,259-3,030	12.3	197	11.6	199	8.1	7.2	4.4	70.5
PHASE IIB -												
May 1-9	0.530	0.43-0.66	2,015	1,559-2,495	16.1	260	11.7	201	8.2	7.2	5.6	90.3
May 10-24	0.523	0.36-0.74	1,980	1,440-2,800	21.5	378	11.4	199	8.1	7.2	5.0	81.2

(1) 61 percent of the HRT is associated with the pulsed aeration compartments
39 percent of the HRT is associated with the continuously aerated compartments.

TABLE 1. OPERATIONAL CHARACTERISTICS

Time Period	MLSS (mg/l)	F/M[1] (g BOD_5/day/g MLVSS)		SRT (days)	Recycle Rate (%Q)	Sludge Production (g BOD_5/day)	SVI (ml/gm)
1977							
PHASE 2A -							
May 5-31	2,340	0.307	0.370	60	177		265
June	2,350	0.340	0.360	41	182	0.44[2]	278
July 1-18	2,480	0.340	0.360	44	200		305
PHASE 2B -							
July 27-31	2,250	0.307	0.330	19	231		218
Aug.	2,530	0.295	0.320	18	190	0.56[2]	234
Sept. 1-9	2,360	0.370	0.380	23	187		242
1978							
PHASE 2A -							
Mar. 30-31	2,360	0.301	0.360	32	204		230
Apr.	2,320	0.360	0.362	20	194	0.73[2]	255
PHASE 2B -							
May 1-9	2,200	0.300	—	32	163	0.65[2]	215
May 10-30	2,230	0.330	—	30	205		242

(1) SS and VSS analyses of mixed liquor samples from Compartments 5-2 and 5-1 for Phases 2A and 2B; from Compartment 5-2 for Phases 2B and 2B.
(2) Average for phase.

TABLE 6. NITROGEN REMOVAL[1]

Time Period	Influent Wastewater Temp. (°C) Avg.	Range	NH_4-N (mg/l) Inf.	Eff.	Org-N (mg/l) Inf.	Eff.	NO_3-N+ NO_2-N (mg/l) Inf.	Eff.	Total -N (mg/l) Inf. Avg.	S.D.[2]	Range	Eff. Avg.	S.D.[2]	Range	% Red.
1975															
PHASE 2A -															
May 5-31	26	11-30	27.9	2.1	32.1	2.5	0.1	4.9	48.7	34.5	27.6-68.1	8.6	2.8	2.1-12.5	78.4
June	30	15-30	30.4	1.3	33.9	2.2	0.1	4.8	42.7	13.5	32.5-61.1	8.3	2.7	2.3-13.7	80.6
July 1-30	28	17-30	34.4	1.7	32.4	2.7	0.3	11.3	47.1	8.3	37.4-58.6	11.7	1.1	10.3-17.5	69.7
PHASE 2B -															
July 27-31	19	15-28	31.7	2.1	33.2	2.3	0.6	1.9	45.5	7.4	34.6-58.4	6.3	1.2	4.2- 7.8	86.2
Aug.	30	19-32	33.1	1.9	33.8	2.4	0.4	2.7	46.6	8.9	32.8-66.1	7.7	2.3	2.3-12.6	83.3
Sept. 1-6	19	19-31	36.1	1.5	11.9	3.7	0.3	4.8	38.8	7.5	32.3-52.3	8.7	1.1	7.4- 9.8	77.1
1976															
PHASE 2A -															
Mar. 10-31	9	9-30	31.*	0.6	30.6	1.7	1.4	5.3	34.9	4.9	30.0-46.2	7.9	2.6	2.5-12.4	72.6
Apr.	30	9-32	31.1	0.3	30.1	1.4	0.8	6.9	38.9	6.1	32.3-52.4	6.6	1.1	2.4-12.8	77.4
PHASE 2B -															
May 1-9	22	13-32	32.8	1.8	34.4	1.5	0.4	7.8	39.8	30.7	28.3-47.8	10.1	1.1	8.4-11.3	71.2
May 10-28	22	12-32	33.7	7.1	15.5	1.4	1.1	5.1	38.3	3.3	33.5-41.8	12.8	2.7	8.1-17.4	67.0

(1) For complete daily nitrogen data see Appendix.
(2) S.D. - Standard Deviation.

TABLE 7. TREATMENT EFFICIENCY

Parameter		PHASE 2A - 1975			PHASE 2B - 1975			PILOT 2B - 1976		PHASE 2B - 1976	
		May 5-31	June	July 1-18	July 27-31	Aug.	Sept. 1-6	Mar. 30-31	Apr.	May 1-6	May 30-31
BOD$_5$ (mg/l)											
Inf. -	Avg.	284	282	323	350	334	365	370	334	337	390
	S.D. (1)	224	236	49	85	97	46	49	50	25	37
	Range	36-539	65-671	84-351	133-380	85-422	68-339	99-301	224-359	242-190	345-373
Eff. -	Avg.	29	5	5	6	8	11	11	7	8	30
	S.D. (1)	33	2	1	2	4	4	3	1	6	6
	Range	3-97	2-11	3-6	4-12	3-19	7-16	5-16	6-11	3-18	19-37
% Reduction		91.3	97.3	98.9	97.1	95.9	93.2	97.0	98.4	94.3	96.1
COD (mg/l)											
Inf. -	Avg.	502	474	393	421	447	391	340	398	351	374
	S.D. (1)	481	335	61	286	240	235	239	182	37	46
	Range	136-2,425	170-2,650	316-423	248-938	204-796	233-917	183-798	198-634	283-637	308-430
Eff. -	Avg.	83	57	55	35	50	79	35	48	36	93
	S.D. (1)	58	39	12	15	24	35	22	23	15	28
	Range	33-301	16-132	34-61	23-57	18-102	47-93	19-71	18-88	25-61	27-94
% Reduction		87.9	88.0	85.3	91.7	87.8	80.1	90.9	87.9	89.7	85.3
SS (mg/l)											
Inf. -	Avg.	223	187	255	234	241	314	340	383	338	381
	S.D. (1)	284	223	78	232	282	44	45	32	22	339
	Range	69-822	46-723	51-[illegible]	109-438	84-889	240-388	183-334	89-272	225-270	138-774
Eff. -	Avg.	23	4	4	5	6	7	27	6	8	35
	S.D. (1)	34	3	2	4	4	3	39	7	2	38
	Range	1-94	1-17	1-7	1-12	1-12	2-12	3-89	1-27	5-8	3-34
% Reduction		94.3	97.3	97.4	97.3	97.3	98.3	93.6	98.3	98.2	92.9

(1) S.D. = Standard Deviation.

SECTION 7

DISCUSSION OF RESULTS

NITROGEN REMOVAL

Single-stage biological nitrification-denitrification was shown to be a viable nitrogen removal process under full-scale plant operation for both summer and winter conditions. Suitable environmental conditions for nitrogen removal were created by simple operational changes and without the supplemental addition of methanol. Wastewater organics proved to be adequate as a carbon source for denitrification in lieu of methanol. By operating at sufficiently low F/M ratios and correspondingly high SRT's under warm and cold weather conditions at HRT's of about 13 to 16 hours and 20 to 24 hours, respectively, stable carbonaceous oxidizing, nitrifying, and denitrifying bacterial populations were maintained. With reference to Table 6, it may be seen that the largest constituent of Total-N in the effluent was generally NO_3-N. Influent and effluent NO_2-N concentrations were negligible. With the exception of the latter part of Phase IIB, effluent NH_4-N levels varied from 0.3 to 2.7 mg/l, indicating a high degree of nitrification. Good removals of Org-N were also consistently achieved. Excluding the period of July 1-16 when lack of available carbon impaired denitrification, nitrogen removals during Phase I averaged 76 to 81 percent with both aeration tanks in service and 77 to 86 percent with one aeration tank in service. In Phase IIA, with two tanks in operation, nitrogen removals averaged about 78 percent. Nitrogen removal was good in the early portion of Phase IIB (one tank in operation) but rapidly dropped to about 50 percent due to the impact of supernatant returns from the overloaded anaerobic digester.

Careful operational control of solids inventory was found to be a major factor in obtaining efficient year-round nitrogen removal. Other important factors were influent characteristics and loadings, including wastewater temperature, COD/TKN ratio, excessive wet weather wastewater flow rates and excessive solids in digester supernatant returns. In late June of Phase IA, the combination of a higher bacterial metabolism rate resulting from increasing temperature, and a lower COD/TKN ratio, resulted in a deficiency of available carbon for denitrification. To reduce the rate at which carbon was consumed during the aerobic cycle, and thus to increase the amount of carbon available during the anoxic cycle, the north aeration tank was removed from service. This resulted in an immediate return of denitrification to previously observed values.

Some problems were encountered in attempting to restore nitrification following a solids washout due to high settling tank loading rates resulting from infiltration/inflow problems in the collection system in late January

between Phases I and II. Although solids were rapidly built back up and the biomass responsible for carbonaceous removal was rapidly reestablished, the nitrifiers were not reestablished until approximately four weeks after the washout. Conversely, denitrifying bacteria were found to be highly responsive and readily established. It appeared that when conditions were favorable for good nitrification efficiency and when an anoxic period and adequate carbon source were provided, a high degree of denitrification was readily achievable.

The failure of the process to efficiently remove nitrogen in Phase IIB is believed to be primarily attributable to the digester problems causing the return of excessive inert solids in digester supernatant and not to temperature effects at lower retention times. Data from the standby period between Phase I and Phase II suggest that single-stage nitrification-denitrification at SRT's of less than 20 days are feasible during winter conditions with adequate operational control. Spot checks indicated that nitrification-denitrification at such SRT's was maintained at wastewater temperatures as low as 11°C with one aeration tank in service until the hydraulic washout of solids in late January. Insufficient data, however, was collected during this standby period to fully evaluate the process under such conditions. Additional research is needed to determine minimum reactor volume under winter conditions.

BIOCHEMICAL OXYGEN DEMAND, CHEMICAL OXYGEN DEMAND, AND SUSPENDED SOLIDS REMOVALS

Process modifications and operational changes performed to create suitable environmental conditions for the nitrification-denitrification process did not adversely affect the plant's ability to remove BOD, COD, and SS. Removal efficiencies were equal or superior to previous plant performance. As shown in Table 7, excellent removals of these three contaminants were consistently achieved throughout the study period until near the end of Phase II when strong digester supernatant returns caused a slight decrease in treatment efficiency. BOD_5 removal efficiency normally ranged from 94 to 97 percent, except during Phase IIB when the efficiency decreased to 86 percent. Effluent COD values over various time periods averaged between 35 and 78 mg/l. As effluent BOD_5 values were consistently less than 10 mg/l, the data suggest that residual COD consisted of mostly refractory material. SS removals generally exceeded 95 percent. On many occasions, equipment and piping objects located 6 to 8 feet below the water surface of the final settling tanks could clearly be seen.

PROCESS MONITORING

Process evaluation prior to initiation of Phase IA was complicated by reliance upon a commercial laboratory for analytical services that utilized a Technicon Auto-Analyzer for COD and nitrogen analyses. After changing to another commercial laboratory, employing manual analytical techniques, results of analyses were much more consistent and reproducible. Excellent correlations on USEPA reference samples were found for analytical results by both the plant laboratory and the second commercial laboratory. Sampling and storage techniques used in the study were evaluated and found to be satisfactory in providing reliable and representative results.

Although no distinguishable differences were found in comparing 24-hour automatically composited samples with 6- and 8-hour manually composited samples, 6- and 8-hour composite samples were collected only as a matter of necessity. It was intended that all influent and effluent samples throughout the study period be 24-hour composites. Unfortunately, the automatic samplers were not delivered as scheduled at the start of the study and operating difficulties were experienced with these samplers when they were put on line. Repeated attempts to obtain servicing of the samplers, although promised by the equipment manufacturer, were rarely successful. This experience points to the importance of the proximity of service facilities as a major criterion to consider in selecting the supplier for any type of process monitoring equipment.

The results of this study indicated that a greater degree of operator supervision, as compared to normal activated sludge system operation, is required as well as a basic understanding of the chemistry and biology of the processes involved. Adequate operational flexibility and controls are necessary to consistently obtain good biological nitrification-denitrification. As nitrification appears to be the most critical of the several processes involved, the operator's attention must be focused on maintaining essentially complete nitrification as a first priority. Once this has been established, attention can be turned to maintaining the correct $\overline{SRT}$ cycle and MLSS concentration needed to produce denitrification.

To assist operators in evaluating process performance for daily operational control purposes, simple daily monitoring techniques readily available to plant operators are needed. As alkalinity determinations are straightforward and readily performed by plant personnel, daily tests were run on influent and effluent samples by plant personnel to evaluate its use as a process monitoring tool. Alkalinity destruction was found to be a good general indicator of the degree of nitrification, as shown in Table 8, and became a useful operating tool. Approximately, 4.2 to 5.4 pounds of alkalinity were destroyed per pound of NH_4-N removed. The table shows an overlap in the percentage of alkalinity destroyed for the degree of nitrification. This probably reflects the formation of alkalinity by denitrification, as the data collected included samples on days with and without denitrification. Based upon a review of alkalinity data obtained for the entire study, it appeared that changes in alkalinity resulting from denitrification were too slight to be used as an indicator of the degree of denitrification obtained. The ranges in alkalinity removal shown apply to Owego and will vary from one location to another, depending on the buffering capacity of different wastewaters.

TABLE 8. RELATIVE DEGREE OF NITRIFICATION AND ALKALINITY REMOVAL

Degree of Nitrification (Percent NH_4-N Removed)	Alkalinity (Percent Removed)
90+	45-65
60-90	30-50
30-60	20-35

As indicated in Table 9, the NH_4-N probe data correlated very well with wet chemistry techniques. As the meter would be used by operators in more of a qualitative rather than quantitative manner, the accuracy of the meter for NH_4-N analysis is more than adequate to be recommended as a daily process performance test.

In contrast, the results were not as encouraging when the analyzer was used to measure NO_3-N. The manufacturer of the meter and probe (Orion Research) advised that an NO_3-N probe could not be used because it was designed for very low concentrations of organic matter. In order to verify this, the manufacturer was supplied with effluent samples for testing using the NO_3-N probe. These results showed that effluent samples, even though efficiently treated, contained sufficient organic matter to render the probe unusable. To measure NO_3-N, the manufacturer recommended that a NO_2-N probe be used with the meter. This necessitated that the sample first had to be passed through a cadmium reduction column to reduce NO_3-N to NO_2-N. Several attempts were made to construct a cadmium column as specified in the manufacturer's manual (7), but the column did not function properly. Even after it was modified, based upon the work of other researchers, it did not effectively reduce NO_3-N to NO_2-N. Moreover, the NO_2-N probe itself did not function properly when used to measure standards. Although it was impossible to completely evaluate this method because of the difficulties experienced with the cadmium column, the entire procedure appears to be unsuitable for use as a daily monitoring tool for plant operators at this time. These difficulties were as follows:

1. Difficulty in controlling the sample flow rate at a specified constant rate as the liquid level in the column varies (flow rate determines contact time and, therefore, degree of reduction).

2. If the contact time is too short, inefficient reduction is obtained. If the contact time is too long, a portion of the NO_3-N reduced to NO_2-N is further reduced to N_2 gas.

3. Frequent flushing with water is required and standards have to be run through the column every fifth or sixth sample.

In summary, a specific ion meter was found to be an excellent monitoring tool for plant operators to evaluate process performance for nitrification, but not for denitrification.

F/M AND SOLIDS RETENTION TIME

The F/M ratio and SRT were found to be important considerations for the design and control of the single-stage nitrification-denitrification system. With both aeration tanks in service, effective nitrogen removal was obtained at an F/M of .06 to .08 g BOD_5/day/g MLVSS in Phase IA (11° to 16°C) and at an F/M of .07 to .08 g BOD_5/day/g MLVSS in Phase IIA (8° to 12°C). With one aeration tank in service, effective nitrogen removal was obtained at an F/M

TABLE 9. LAION PROBE VS. WET CHEMISTRY FOR NH_4-N MEASUREMENTS

Date	NH_4-N (mg/l) Wet Chemistry	Probe	Date	Wet Chemistry	Probe
11/19/75	23.5*	22.0	3/19/76	15.5	16.0
	1.5	1.3		0.5	< 1.0
12/5/75	23.4	25.0	3/22/76	14.5	15.0
	1.5	1.2		0.8	< 1.0
12/15/75	30.0	32.0	3/23/76	15.6	16.0
	0.5	< 1.0		0.3	< 1.0
12/19/75	26.5	29.0	3/24/76	18.5	18.0
	0.8	< 1.0		0.4	< 1.0
3/10/76	23.7	27.0	3/25/76	20.0	20.0
	1.0	1.7		0.4	< 1.0
3/11/76	17.2	20.0	3/26/76	14.5	15.0
	N/A	1.2		0.2	< 1.0
3/12/76	17.9	21.0	4/5/76	15.1	13.8
	1.0	1.0		0.6	< 1.0
3/15/76	16.5	17.5	4/6/76	23.9	24.0
	0.7	< 1.0		1.3	< 1.0
3/16/76	15.6	15.5	4/7/76	22.3	21.0
	0.5	< 1.0		0.7	< 1.0
3/17/76	16.0	16.5	4/8/76	19.7	19.0
	0.5	< 1.0		0.7	< 1.0
3/18/76	20.5	20.0	4/9/76	24.2	22.0
	0.7	< 1.0		0.7	< 1.0

*For each date first entry is raw wastewater, and second entry is final effluent.

of .10 to .13 g BOD_5/day/g MLVSS in Phase IB (18° to 22°C) while inefficient nitrogen removal was obtained in Phase IIB (11° to 13°C). Although the period of operation in each phase was not equivalent to three times the estimated operational SRT for that period as required by the rule of washout curves to establish stable operation, essentially stable operation was indicated in Phases IA, IB, and IIA by the consistency of effluent parameters such as COD and NH_3-N. Based upon this, the data suggest that SRT's between 41 and 69 days in Phase IA, between 20 and 32 days in Phase IIA, and between 13 and 19 days in Phase IB resulted in effective nitrogen removal. Stable operation was not achieved in Phase IIB at an estimated SRT of 10 to 12 days. The lower SRT's during Phase II, particularly during Phase IIB, were due primarily to the increased rate of sludge wasting necessitated by inefficient anaerobic digester operation and return of digester solids to the aeration tank. By maintaining the MLSS at the desired level of approximately 3,000 mg/l, the input of digester solids probably resulted in a lower fraction of active microbial mass during Phase IIB and, thus, a net loss of some nitrifying bacteria. Due to plant staffing problems, no measurements were made to determine the volatile fraction of MLSS during this period. It is doubtful that such data, even if available, would have been useful because the type of volatile solids in the system was far different than during normal process operation.

The loss of nitrification in Phase IIB with one aeration tank in service at colder temperatures appears to have been due to inadequate solids inventory or SRT. Calculations, based upon the bench scale determination of kinetic rate at 12°C, indicated that the solids inventory was marginal for complete nitrification to occur. A decrease in the fraction of active mass because of the digester solids returns would have dictated an increase in the solids inventory required for complete nitrification, assuming sufficient SRT. It seems unlikely that the system failed because of insufficient SRT at 12°C, causing a washout of the nitrifiers. A previous steady-state laboratory study (6) found that the limiting value of minimum SRT for nitrification is approximately four days at 8°C. During May 1976 the Owego plant was operated at SRT's of 10 to 12 days at temperatures of 11° to 13°C. Results from other full-scale studies (11) indicated that at 12°C, SRT's of 10 to 12 days should have been adequate.

Nevertheless, it is important that a sufficient inventory of aerated solids based upon aerobic cycles be provided with an adequate safety factor (6) to ensure complete nitrification at the lowest temperature conditions to be encountered.

The results indicate that single-stage nitrification-denitrification can be operated over a wide range of SRT's with only a minimal amount of monitoring required and only minor adjustments in plant operation for most of the year. At temperatures of 8° to 16°C during Phases IA and IIA, the plant was effectively operated at SRT's ranging from 20 to 69 days. At higher temperatures, a major reduction in solids inventory was required to achieve effective denitrification.

In summary, it appears that SRT's between 20 and 30 days were best for wastewater temperatures between 8° and 15°C. For temperatures between 15°

and 22°C, SRT's of 15 to 20 days were sufficient. The process functioned well at longer SRT's (40 to 60 days) except during peak summer temperatures when carbon deficiency problems occurred due to excessively rapid carbon removal during the aerobic cycle. Operation at longer SRT's in warm weather may be feasible by reducing the aerobic cycle time and increasing the anoxic cycle time. However, the success of this approach would depend upon the ability to maintain adequate aerobic HRT for nitrification. Although additional research is needed to determine the optimum F/M ratio and SRT under various conditions, the results at Owego appear to compare reasonably well with other recent studies for single-stage nitrogen removal.

DISSOLVED OXYGEN

Operational variables related to oxygen supply include DO ranges and aerator cycling times. DO profiles were routinely performed to assist in monitoring and evaluating process performance. The DO levels in Compartments N-1 and S-1 were generally maintained between 1 and 2 mg/l during the on-cycle in the early phases of the study period. As the study proceeded, it appeared that DO levels nearer to 1 mg/l were preferable and gave somewhat superior performance as this did not appear to inhibit nitrification, but enhanced denitrification by shortening the lag period to reach anoxic conditions during the off cycle.

The mechanical aeration equipment was operated so that periodic adjustments could be made to compensate for gradual changes in temperature, which affected aerator oxygenation rates. As wastewater temperatures increased, biological activity increased and oxygenation capacity decreased causing a gradual drop-off of DO during the aerobic cycle. Additional oxygenation was readily obtained by raising the aeration tank effluent weir level.

DO levels of less than 1 mg/l during the aerobic cycle may be adequate, depending on seasonal conditions. An operating DO level of 0.7 to 1.0 mg/l appeared to be satisfactory, but time did not permit extensive study of this aspect, and additional work to optimize DO levels may be worthwhile.

SLUDGE SETTLEABILITY

Excellent removals of SS were consistently achieved throughout the entire study indicating that the process did not adversely affect solids removals. Column settling tests were conducted periodically to monitor changes in settleability and to provide data for estimating settling tank capacity in future designs.

It is worth noting that a sludge bulking condition had developed in July 1974, about six months prior to the process changes that were made in January 1975 in anticipation of the study. Prior to July 1974, 30-minute sludge settling tests in a 1-l graduated cylinder normally resulted in interface levels of 200 to 500 ml. For no apparent reason, these increased to 900 to 1,000 ml in July 1974 and, regardless of the process changes made prior to and during the study, remained in the same range. Thus, the effect of single-stage nitrification-denitrification on sludge settleability, whether positive or negative, could not be determined.

The results of typical column settling tests under warm and cold weather conditions are shown in Figures 8 and 9, respectively. During Phase I, a 1-l graduated cylinder was used for settling tests. The curve in Figure 8 shows that the floc settled well and that the settling rate was 0.8 m/hr (2.7 ft/hr) in warm weather. During Phase II, a 10-l column was used for settling tests. The curve in Figure 9 shows that there was an apparent bulking condition during cold weather. Typically, there was a 30- to 60-minute delay before the solids would begin to settle, and the rate was much lower than during summer. Although on occasion floating solids were observed in the final settling tanks, they did not escape over the weirs. Figure 10 is a picture of a column settling test showing the floating solids.

Under warm weather conditions and at MLSS concentrations of 2,500 to 3,500 mg/l sludge settling rates fell between 0.46 and 1.04 m/hr (1.5 and 3.4 ft/hr). However, no correlation between MLSS concentration and settling rate was observed.

Based on settleability data observed after the 30- to 60-minute delay period at similar MLSS levels during winter conditions, sludge settling rates ranged from 0.18 to 0.49 m/hr (0.6 to 1.6 ft/hr). The lower values, when converted directly to equivalent surface overflow rates, indicated that the sludge should not have settled at the rates actually occurring in the settling tank. However, no loss of solids from the tanks was observed indicating that the 6- to 7-hour tank detention time was an important factor in solids capture.

SLUDGE WASTING AND RECYCLING RATES

Sludge wasting procedures were intended to maintain a MLSS level of 3,000 mg/l, although in actual operation MLSS normally ranged between 3,000 and 4,000 mg/l. The required sludge wasting rate for Phase IA was estimated to be 0.44 g/g BOD_5 removed. In Phase IB, the sludge production rate increased to 0.76 g/g BOD_5 due to the reduction in solids inventory and, consequently, the SRT. Sludge wasting rates in Phase IIA and IIB were estimated to be 0.71 g/g BOD_5 removed and 0.98 g/g BOD_5 removed, respectively. Although the plant was operated at similar F/M ratios during both phases, the sludge wasting rate had to be increased in Phase II to maintain the desired MLSS levels. This increase in sludge wasting was probably necessitated primarily by the increased return of inert solids in digester supernatant, as well as by the usual increase in synthesized carbon which usually occurs at colder temperatures.

The sludge recycle flow was held fairly constant over the entire study period. No attempt was made to determine the effects of a range of recycle rates on nitrogen removal. The data suggest that increased nitrogen removal can be attained at higher sludge recycle ratios. Analysis of data collected during the study showed that additional nitrification was achieved in the continuously aerated compartments following the cycled compartments. Since little denitrification occurred in the plant after that point, NO_3-N was normally the largest constituent of total-N in the effluent. By increasing the sludge recycle rate, additional denitrification of nitrates contained in the return sludge supernatant may be achieved, thereby

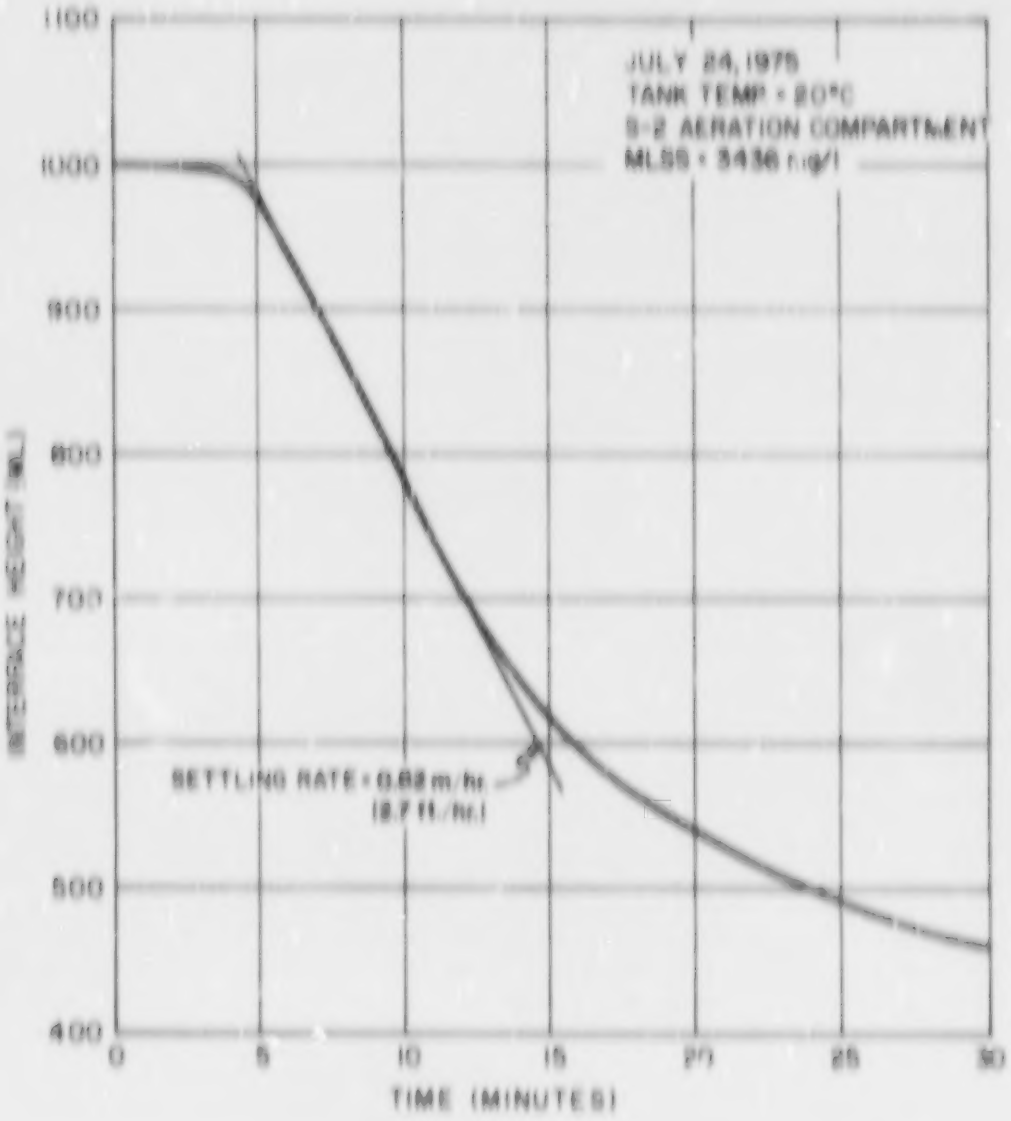


FIGURE 5. COLUMN SETTLING TEST (WARM WEATHER)

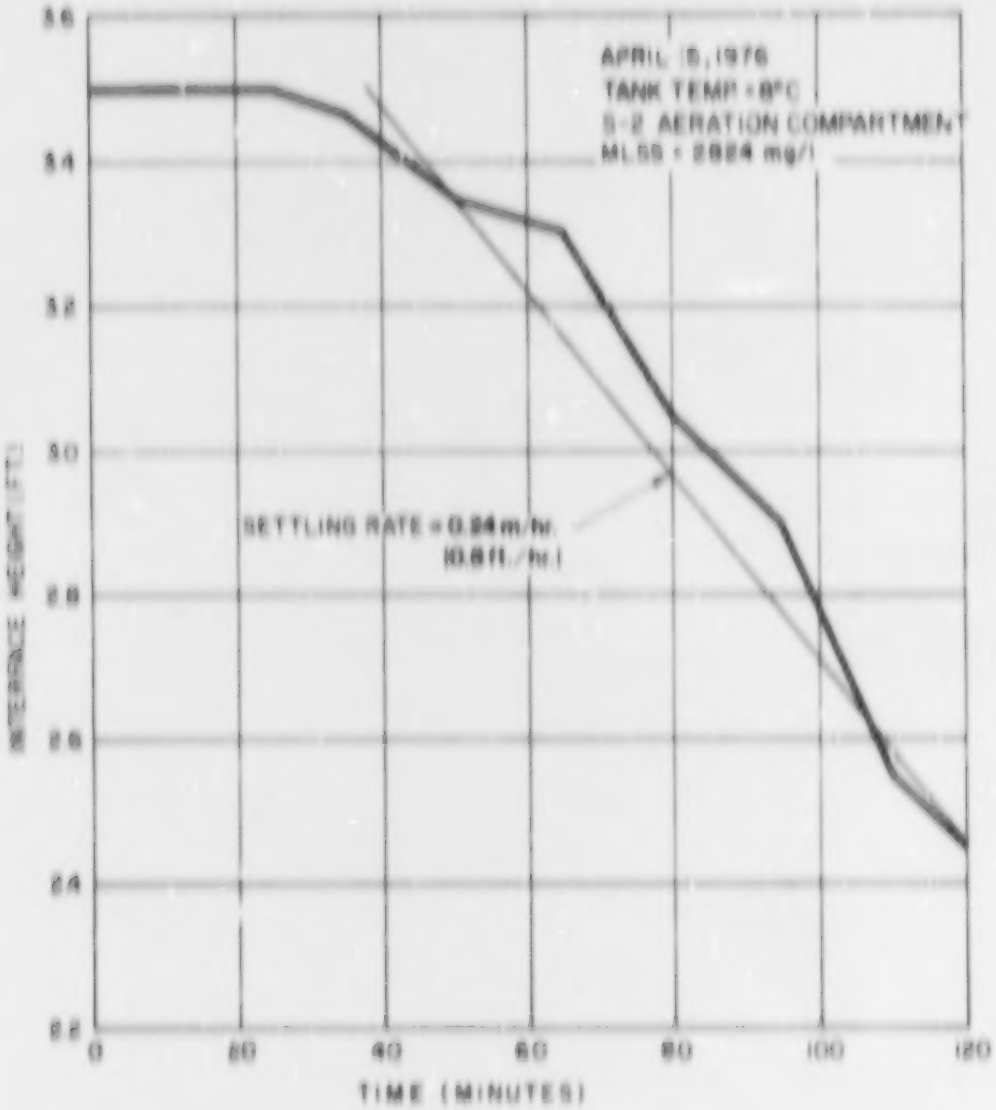


FIGURE 9. COLUMN SETTLING TEST (COLD WEATHER)

FIGURE 10. FLOATING SOLIDS IN COLUMN SETTLING VESSEL

increasing the quantity of nitrates removed across the plant. Additional research is needed to investigate the benefits of high recycle rates as a tool to increase denitrification.

ANAEROBIC DIGESTER SUPERNATANT

Samples were randomly taken from the digesters to determine the strength of digester supernatant returns. As shown in Table 10, analyses of samples collected in Phase I indicated that the digesters were operating well and a weak supernatant was being returned to the head of the aeration tanks. No detrimental effects were observed. On an average weekly basis, the supernatant return contributed at most an additional 4 percent to the normal influent BOD_5, COD, and SS loadings. TKN from supernatant returns contributed an additional 5 to 13 percent to the normal influent TKN loading. Similar analyses during Phase IIB indicated that supernatant returns had become stronger due to the cessation of digested sludge removal from the one digester. During Phase IIB it was estimated that digester supernatant returns accounted for an additional 31 to 36 percent increase in the normal influent BOD_5, TKN, and SS loadings and approximately an 18 percent increase in the normal COD loading. Of course, the supernatant returns were a shock loading because sludge wasting, with corresponding equal volume displacement of supernatant, and subsequent return to the head of the aeration tank was normally practiced three times per week over a period of a few hours. Thus, during the actual period of wasting, the supernatant return represented a 300 to 600 percent increase in the total loading on the aeration tanks.

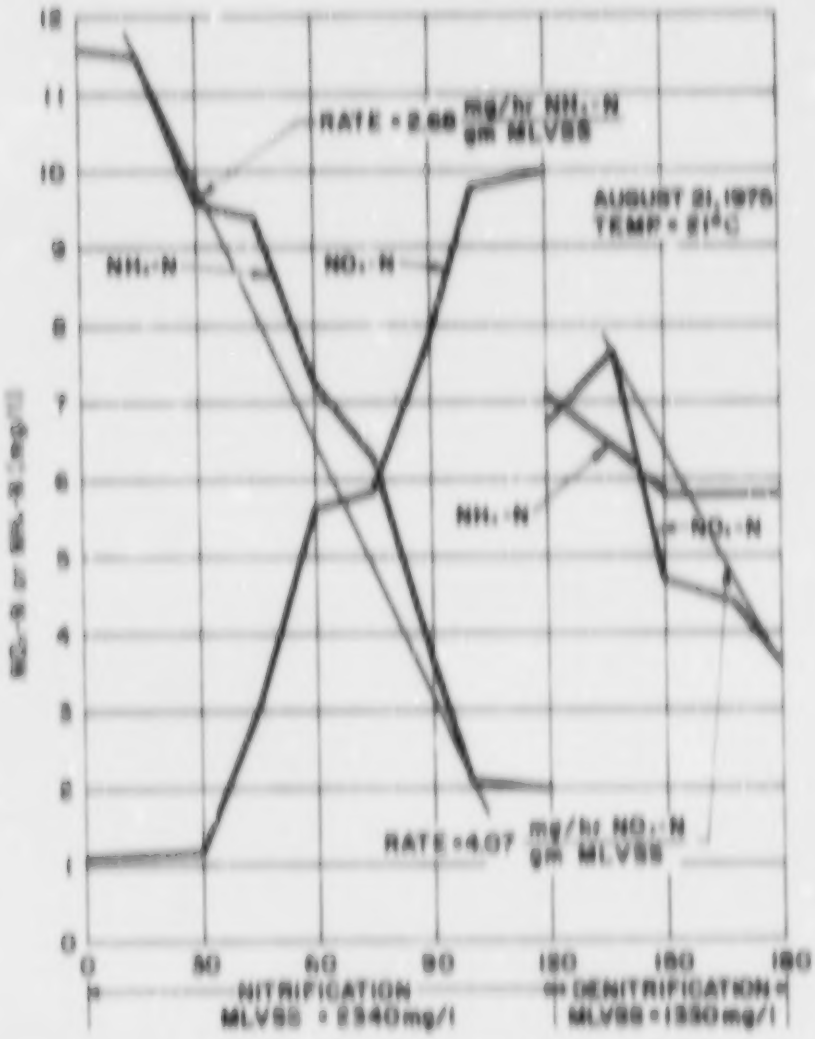
TABLE 10. SECONDARY DIGESTER SUPERNATANT CHARACTERISTICS

Phase	Number Of Samples	Average Concentration (mg/l) BOD_5	COD	SS	TKN
IA	7	189	380	93	235
IB	8	200	371	---	155
IIA	0	---	---	---	---
IIB	1	1,150	1,490	1,240	217

The digester supernatant problems that occurred during Phase IIB are a classic example of the importance of avoiding excessive storage of solids in digestion tanks and the adverse effects of heavy supernatant returns on the operation of biological treatment systems.

KINETIC RATE TESTS

Several batch laboratory nitrification-denitrification kinetic rate tests were conducted during the study. Data obtained from one such test performed under summer conditions are plotted in Figure 11. The Figure clearly shows the occurrence of nitrification during the aerobic stage and denitrification during the anoxic stage. The sudden changes in NO_3-N



TECHNIQUE REFER TO "SPECIAL TESTS, ITEM #3" pg. 21

FIGURE II NITRIFICATION - DENITRIFICATION RATE TEST

and NH_4-N concentrations at T = 120 minutes, resulting in the discontinuous curves, reflect the addition of fresh influent wastewater at that point to provide a source of carbon for denitrification.

Two preliminary tests were conducted prior to the August 21, 1976 test to establish rate testing procedures. The data obtained from these tests has not been presented, as samples were taken only at 1-hour intervals and, therefore, did not provide an adequate number of data points for kinetic rate determinations. In all subsequent tests, sampling was conducted at 15-minute intervals.

Data from the 15-minute interval tests are presented in Table 1. As expected, the nitrification rates observed at lower temperatures were lower than those observed at higher temperatures. To the contrary, the denitrification rate observed at 14°C was higher than that observed at 21°C. Three factors appeared to contribute to this phenomenon:

1. As the reduction of NO_3-N in any given test varies considerably from a straight-line slope, the denitrification rate calculated can vary depending upon which portion of the test data is used. For example, in the August 21, 1975 test plot shown, the calculated rate included the flatter portion of the curve from 150 to 180 minutes. If only the steep portion (T = 135 to 150 minutes) had been used, the calculated rate would have been approximately trebled.

2. In comparing the kinetic studies conducted, residual COD values varied widely from test to test during the denitrification step. Thus, the unexpected results in the calculated denitrification rates may be due to differences in available carbon. Beginning at T = 150 minutes of the August 21, 1975 test, COD values decreased to a level approaching that of plant effluent COD. This suggests that the more readily oxidizable carbon had been utilized during the aerobic stage, leaving little available carbon for denitrification. In the other tests conducted, residual COD values during the denitrification step were higher, indicating that greater amounts of unoxidized carbon were available for denitrification.

3. The August 21, 1975 test was conducted in a 9.5-l (10-qt) pail, while the April 29, 1976 test was conducted in a 10.5-cm diam x 122-cm high (4-1/8-in. diam x 48-in.) plexiglass column. It is conceivable that denitrification in the pail, which was stirred during the anoxic portion of the test, could have been slowed by the introduction of atmospheric oxygen into the pail while it was being stirred.

TABLE 11. LABORATORY BATCH NITRIFICATION-DENITRIFICATION KINETIC RATES

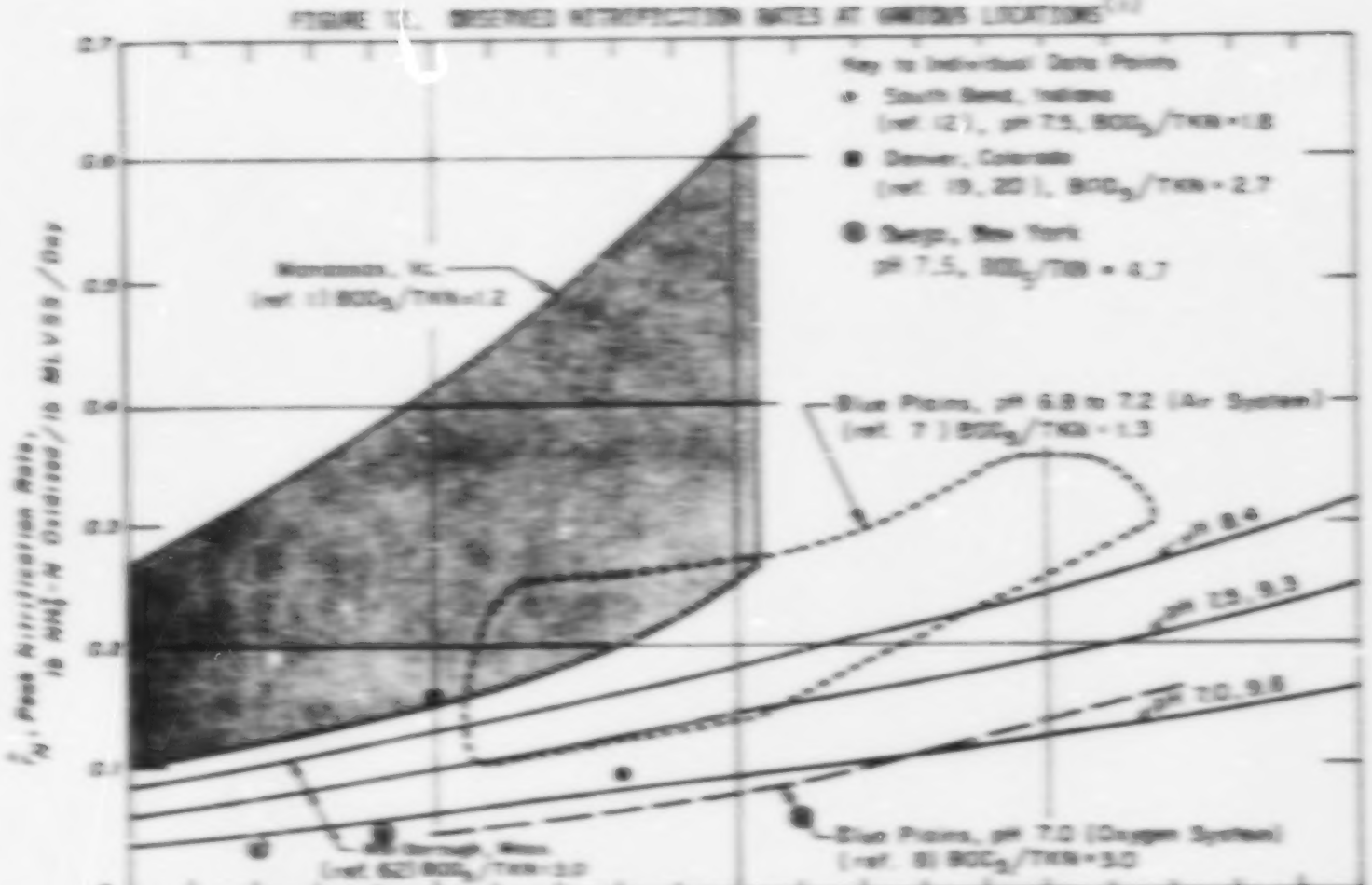
Date	Temperature, °C	Kinetic Rate Constant[a] Nitrification ($\frac{g\ NO_3\text{-}N/day}{g\ MLVSS}$)	Denitrification ($\frac{g\ NO_3\text{-}N/day}{g\ MLVSS}$)
8/21/75	21	0.064	0.097
3/23/76	12	0.032	---
4/29/76	14	0.047	0.170

[a] Cycle of aerobic-anoxic operation--2 hours aerobic, 1 hour anoxic.

With reference to Figure 11, it can be seen that nitrification continued during the first 15 minutes of the anoxic portion of the test. This can be explained by the fact that residual DO was available for nitrification for a short time after aeration was stopped. This DO was soon utilized, and no significant nitrification occurred during the remainder of the anoxic cycle. The data from this test also suggest that the denitrification rate decreased as the supply of readily oxidizable wastewater organics was depleted. At T = 120 minutes, after the addition of fresh influent, the COD was 146 mg/l; and at T = 150 minutes the COD was 67 mg/l. In addition, the relatively low concentration of NO_3-N (approximately 4 mg/l) available for denitrification may have also affected the kinetic rate.

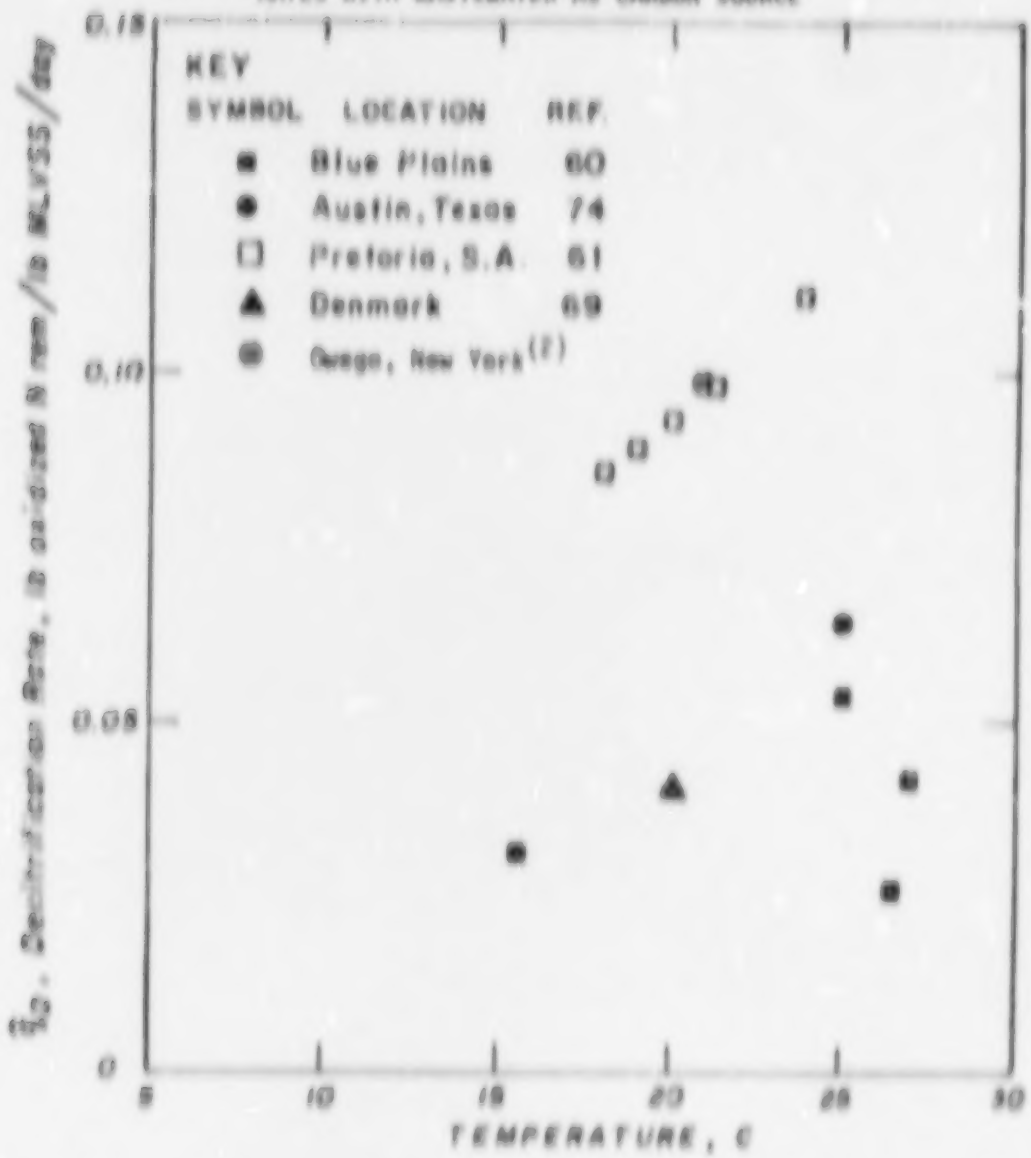
Several limitations were encountered with the methodology employed for batch kinetic studies. Because a large laboratory reaction vessel was needed to provide adequate sample volumes for analytical purposes, a water bath could not be used to maintain a constant temperature in the reaction vessel. With warmer wastewater the temperature remained fairly constant; however, during the winter the temperature inside the vessel gradually increased over the 3-hour test period. A second limitation of the testing procedure was that nitrification continued during the beginning of the anoxic cycle utilizing the residual DO, thereby increasing the NO_3-N concentration. At the same time, some denitrification had started, thereby decreasing the NO_3-N concentration. Thus, the observed decrease in NO_3-N concentration used to determine the kinetic rates may have been larger than was apparent. DO concentrations during the aerobic cycle in the laboratory reaction vessel were significantly higher than those in the aeration tanks due to the relative shallowness of the laboratory test vessels. The need to control laboratory air flow to maintain sufficient agitation for liquid-solids contact resulted in higher DO levels in the test vessels.

Observed nitrification and denitrification rates from these studies are compared to the results of similar studies (11) in Figures 12 and 13. Considering the variability of wastewater from one location to another and the inherent limitations of the methodology employed, the kinetic rates determined are in reasonable agreement. As pointed out in other studies (6), a kinetic rate based upon MLVSS is of limited usefulness as a general design criterion for nitrification and denitrification systems. Since the predominant fraction of a mixed bacterial culture in a single-stage system consists of carbonaceous heterotrophic organisms, and only a small fraction


Key to Individual Data Points
South Bend, Indiana
(ref. 12), pH 7.5, $SOD_5/TKN = 1.8$
Denver, Colorado
(ref. 19, 20), $SOD_5/TKN = 2.7$
Largo, New York
pH 7.5, $SOD_5/TKN = 4.7$
Monsanto, NC.
(ref. 1) $SOD_5/TKN = 1.2$
Blue Plains, pH 6.8 to 7.2 (Air System)
(ref. 7) $SOD_5/TKN = 1.3$
pH 8.4
pH 8.3
pH 7.0, 9.8
Blue Plains, pH 7.0 (Oxygen System)
(ref. 8) $SOD_5/TKN = 3.0$
TEMPERATURE, C

[1] Source: USEPA "Process Design Manual for Nitrogen Control" (11).

FIGURE 13. EFFECT OF TEMPERATURE ON PEAK DENITRIFICATION[1] RATES WITH WASTEWATER AS CARBON SOURCE



(1) Source: USEPA "Process Design Manual for Nitrogen Control" (11).
(2) Denitrification rate at 14°C is off scale of plot.

of the MLVSS are nitrifiers and denitrifiers, the proportion of nitrifiers and denitrifiers in the sludge mass cannot be accurately estimated and is largely dependent upon the influent COD/TKN ratio and process loading conditions. Even for identical systems operating under similar temperature conditions, measurements will vary from one location to another, depending on influent wastewater characteristics. Thus, the use of kinetic rates as a design criterion is dependent upon local conditions. Notwithstanding these limitations, the data indicate that nitrification, and not denitrification, is the rate limiting step and will exert the greatest impact on reactor sizing.

OXYGEN REQUIREMENTS

Calculations of the theoretical oxygen demand necessary for carbonaceous oxidation and nitrification are compared to estimates of the actual amounts of oxygen supplied by the mechanical aerators in Table 12, based upon actual BOD_5 and TKN removals. The results indicated that the actual amount of oxygen supplied exceeded theoretical amounts required in Phases IA and IIA with both aeration tanks in service; but in Phases IB and IIB with one aeration tank in service, the actual amounts of oxygen supplied were less than theoretical requirements. Nevertheless, efficient removal of BOD_5 and efficient nitrification were achieved in Phase IB, and DO levels were adequate indicating that the oxygen supply to the system was not deficient.

As would be expected for a system of this type, the data indicate that the amount of oxygen required for single-stage nitrification-denitrification is less than that required in a nitrifying activated sludge system. Calculations of theoretical oxygen requirements did not take into account the fact that a portion of the influent organic carbon acted as the electron donor and was stabilized during the denitrification process, while the nitrate radical acted as the electron acceptor. Thus, oxygen supplied by the mechanical aerators for nitrification is reused during denitrification to oxidize a substantial portion of the influent organic material. The resultant reduction in energy input required represents a potential operating cost savings when employing both nitrification and denitrification in a single-stage system.

COD/TKN

The ratio of carbonaceous material to nitrogenous material as reflected by the ratios of BOD_5/TKN and COD/TKN is believed to have a significant effect upon single-stage nitrification-denitrification. The primary settling tanks were removed from service prior to the start of the study to increase the COD/TKN ratio and, therefore, maximize the availability of carbon needed for denitrification. Previous studies (3) had found that when the COD/TKN ratio was reduced from 10 to 7.5, nitrogen removal was reduced. Although no attempt was made to vary the COD/TKN ratio to study its effects, an unexplained temporary decrease in the COD/TKN ratio is believed to have been a contributing cause to a reduction in the degree of denitrification achieved in Phase IA. From July 1-16, the COD/TKN ratio was 6.6, compared to a normal COD/TKN ratio of about 10. The unusually low influent COD loading probably contributed to the carbon deficiency during denitrification noted during this

TABLE 5. [illegible]

Time Period	Theoretical BOD*		Theoretical NOD**		Total O_2 Demand		Actual O_2 Supplied						Ratio of Actual to Theoretical
							1st Stage		2nd Stage		Total		
	Ibs/day	kg/day	Ibs/day	kg/day	Ibs/day	kg/day	Ibs/day	kg/day	Ibs/day	kg/day	Ibs/day	kg/day	
1975													
PHASE IA -													
May 1-31	1,021	461	488	221	1,509	684	740	336	1,465	671	2,205	1,007	1.46
June	1,021	463	535	243	1,556	706	733	333	1,436	649	2,169	982	1.39
July 1-09	734	333	613	278	1,347	611	633	278	1,073	737	2,106	1,015	1.56
PHASE IB -													
July 31-31	1,021	463	535	243	1,556	706	425	193	833	378	1,258	571	0.81
Aug.	1,015	460	703	319	1,718	779	451	205	808	378	1,259	571	0.73
Sept. 1-8	878	398	581	264	1,459	662	429	194	830	376	1,259	571	0.86
1976													
PHASE IA -													
Dec. 31-31	1,200	545	773	349	1,981	894	825	372	1,630	740	2,470	1,120	1.26
Apr.	1,155	524	713	323	1,868	847	825	372	1,656	749	2,470	1,120	1.27
PHASE IB -													
May 1-8	1,030	470	618	280	1,708	771	425	288	833	372	1,220	558	0.72
May 10-09	1,210	549	525	238	1,735	787	410	280	825	372	1,235	560	0.71

* Theoretical Carbonaceous O_2 Demand = 1.1 x BOD_5 Removed.
** Theoretical Nitrogenous O_2 Demand = 4.6 x TKN Removed.

period. However, because the changeover from two to one aeration tanks on July 16 resulted in such an abrupt improvement in denitrification, it is believed that excess biomass was the more important cause of the temporary loss of denitrification.

MIXING

One of the initial concerns of the study related to the loss of liquid-solids contact during the anoxic denitrification cycle due to partial settling of mixed liquor in the aeration tanks when the mechanical aerators were off. During the 30-minute anoxic cycle the liquid-solids interface subsided to a depth of approximately 0.6 to 1.2 m (2 to 4 ft) in warm weather and 0.3 to 0.6 m (1 to 2 ft) in cold weather. The residual rolling action remaining from the aerator on cycle was sufficient to suspend the floc to a large extent. Adequate liquid-solids contact for efficient denitrification was achieved under both winter and summer conditions because of the number of cycles influent wastewater underwent prior to discharge from the aeration tanks. Under the worst conditions, i.e., liquid-solids interface depth at 1.2 m (4 ft) and one aeration tank in service, the probability that each influent particle of water came into contact with solids for at least one anoxic cycle is greater than 99 percent. Therefore, the partial lack of liquid-solids contact did not appear to adversely affect denitrification even during warm weather when the contact zone was shallowest.

PHOSPHORUS REMOVAL

Total phosphorus analyses were conducted on a 5-day basis for the period of April 24, 1975 to June 4, 1976 to determine the effects of single-stage nitrification-denitrification on phosphorus removal. As anticipated, there was no discernible effect of the process on phosphorus removal. Prior to pulsing of the aerators, phosphorus was reduced from an average of 9.9 mg/l to 5.5 mg/l, or 44 percent removal, based upon seven composite samples analyzed. After pulsing, phosphorus was reduced from an average of 9.6 mg/l to 4.7 mg/l, or 51 percent removal, based upon 22 composite samples analyzed. This apparent improvement was not considered significant because of the wide variations in both influent and effluent samples.

SEPTAGE AND SIPHON FLUSHING

In addition to digester supernatant returns and high flow rates from infiltration and inflow, shock loads were contributed to the aeration tanks by septic tank truck dumping and periodic flushing of the Susquehanna River siphon. Table 13 lists the quantities of septic wastes received at the treatment plant and the frequency of flushing the Susquehanna River siphon. No adverse effects from septage and siphon flushing were apparent on the nitrification-denitrification process.

TABLE 13. SEPTAGE AND RIVER SIPHON FLUSHING

Month	Septage		Siphon
	cu m/month	gal/month	(times flushed/month)
April 1975	45.6	12,100	---
May 1975	89.4	23,600	---
June 1975	82.5	21,800	0
July 1975	46.2	12,200	3
August 1975	21.6	5,700	2
September 1975	51.9	13,700	1
October 1975	39.8	10,500	14
November 1975	50.4	13,300	12
December 1975	26.9	7,100	14
January 1976	23.9	6,300	13
February 1976	37.9	10,000	12
March 1976	40.9	10,800	14
April 1976	22.7	6,000	13
May 1976	22.3	5,900	12

SECTION 8

DESIGN AND OPERATING CONSIDERATIONS

Although more research work is necessary to provide additional data and process methodology for design, a number of important design and operating considerations were revealed by the study.

PRIMARY SETTLING TANKS

In determining whether or not to use primary settling tanks ahead of a single-stage nitrification-denitrification system, the following should be considered:

1. The use of primary settling will reduce the COD/TKN ratio of the aeration tank influent and thus may reduce the degree of denitrification attainable. However, it is possible that soluble COD may be of considerably more importance than total COD. If so, the removal of particulate COD in primary tanks may not have an adverse effect on denitrification.

2. Reduction in biological reactor volume requirements.

3. Reduction in rag accumulations on aeration equipment.

4. Reduction in scum accumulations in biological reactor and final setting tanks.

5. Benefits associated with capture of solids from septic tank wastes, digester supernatant, thickener overflow, and sewer flushings.

REACTOR DESIGN

The following considerations are offered relative to reactor sizing and configuration:

1. Reactor volume must be adequate for complete nitrification. Additional volume must be allowed for denitrification, as well as for lag periods while DO is being depleted at the initiation of denitrification.

2. Provision should be made for maintaining DO in the final settling tank influent at all times.

3. If wastewater temperatures vary seasonally, flexibility should be provided to adjust operating reactor volume to maintain optimum process performance.

4. Each reactor should be compartmentalized to segregate aerobic from anoxic or alternating anoxic-aerobic sections. Provision should be made to introduce feed to each compartment and to divide feed among compartments.

AERATION AND MIXING EQUIPMENT

1. Aeration equipment must be sized to provide the amounts of oxygen necessary for complete carbonaceous and nitrogenous oxidation, and have the flexibility to deliver the total amount of oxygen needed into the tankage on-line under each seasonal situation.

2. Although surface mechanical aeration will achieve satisfactory results, consideration should be given to aerator designs that will provide mixing during the anoxic cycle to ensure complete contact with unoxidized carbon entering the reactor.

3. Automatic controls must be provided to control the duration of the aerobic and anoxic cycles. For surface mechanical aerators, simple 1- to 2-hour repeat cycle timers appear adequate. For diffused or combined turbine-sparger systems, timed valve controllers can be used to rotate the air feed from one tank to another, or to start and stop air blowers.

FINAL SETTLING TANK

1. Tanks must be provided with low surface overflow rates to prevent solids washout at high flows and be sufficiently deep to allow for diurnal blanket level variations without solids carryover due to weir velocity effects. Current design criteria for extended aeration settling tanks (12) should not be exceeded and more conservative criteria may be warranted.

2. Separate sludge return pumps and suction lines should be provided for each settling tank.

3. Return sludge capability of 200 percent appears desirable with systems employing MLSS operating levels above 3,000 mg/l.

4. Flow meters should be provided for both return and waste sludge.

5. Multiple effluent weir designs which create high velocities between weir troughs, or between the trough and the tank wall, should be avoided.

SLUDGE PROCESSING

1. Although well-operated anaerobic digesters should pose no problem, consideration should be given to aerobic digestion as the character of aerobic digester supernatant returns may be more compatible with process operation.

2. Allowance should be made in reactor design for the TKN content of returns from sludge processing operations.

PROCESS OPERATION AND CONTROL

1. Essentially complete nitrification must be achieved at all times.

2. The existence of nitrification can be monitored by alkalinity measurements or preferably by the use of an NH_4-N meter and probe.

3. The presence of denitrification is best monitored by nitrate analysis, but alkalinity changes may be of assistance as an indication. The most desirable tool would be a reliable and simple probe-type measuring device for NO_3-N.

4. Solids inventory and attention to solids wasting are the main factors in maintaining proper F/M and SRT.

5. DO concentrations of greater than 1 mg/l during the aerobic cycle do not appear necessary. Substantially lower levels may inhibit nitrification while higher levels may delay the onset of denitrification at the beginning of the anoxic cycle.

6. Clarifier sludge blanket level measurement as well as 30-minute settling tests on return sludge are desirable to avoid under-pumping of return sludge.

7. Operators must understand the fundamentals of each major process involved and the basic process interrelationships. Normally, once the proper solids inventory, wasting rate, cycle time and oxygen level have been established, the process appears to perform in a stable manner.

SECTION 9

FUTURE RESEARCH

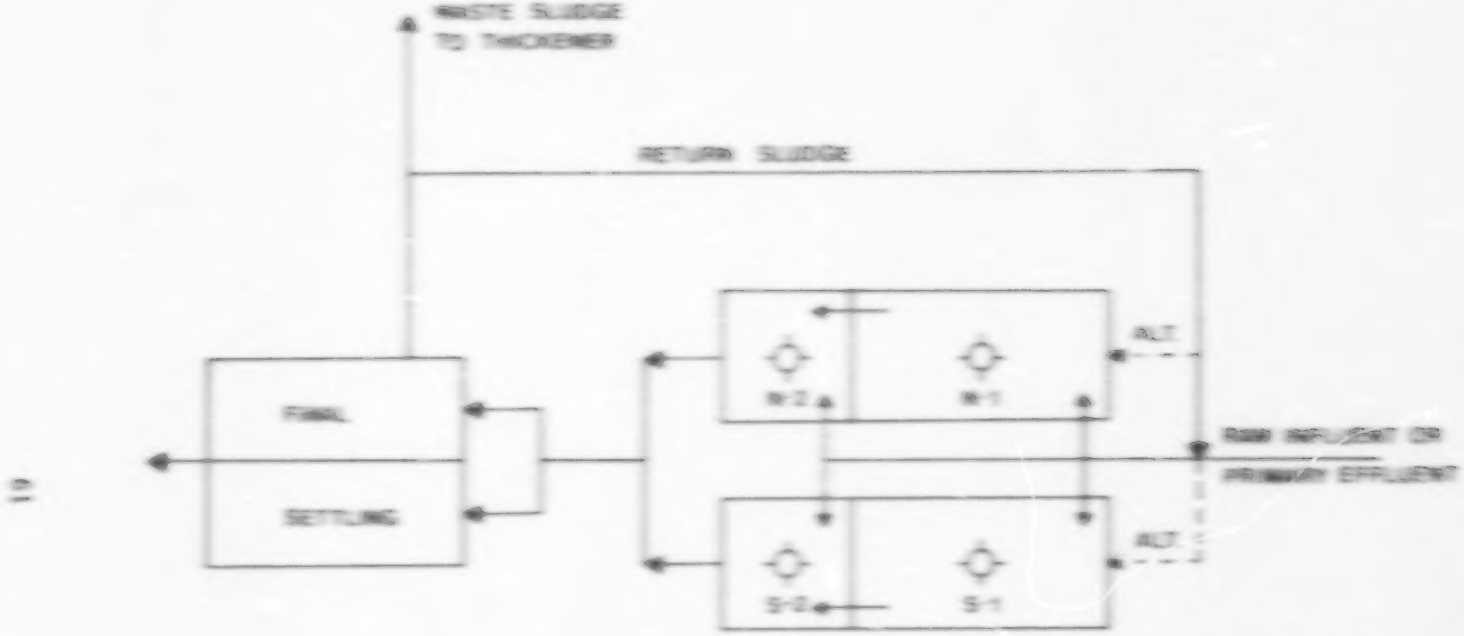
In reviewing the overall procedures and results of this study, several areas can be identified where additional research would be of great assistance in a better understanding of the process and an improvement in design and operating techniques.

At Owego, the following additional research objectives appear desirable:

1. Potential improvements in nitrogen removal by feeding and intermittently aerating the second compartment (see Figure 14).
2. Examine the effect of primary settling on nitrogen removal.
3. Evaluate nitrogen removal at high sludge recycle rates.
4. Evaluate benefits of continuous mixing during anoxic cycle.
5. Obtain additional data on process design criteria and cold weather performance.
6. Evaluation of cadmium reduction column and NO_2-N probe to monitor denitrification.

Before a new concept such as single-stage nitrification-denitrification will be accepted by the design profession as a viable alternate to currently established nitrogen removal processes, proof of the universal merits of the process, by testing at other full-scale plants, is highly desirable. In addition to providing additional data on process reliability, performance and design technology, the selection of appropriate existing plants could also provide the following information:

1. The adaptability of diffused aeration equipment to the process.
2. The degree of nitrogen removal achieved by "ditch-type" activated sludge plants and the development of design techniques to maximize removals.
3. Performance levels attainable by turbine-sparger aeration equipment.
4. For very warm climates, whether or not premature carbon consumption can be controlled to avoid the loss of denitrification.



NOTE: 1. ADD PART OF INFLUENT WASTEWATER TO AERATORS N-2 & S-2.

2. ALL AERATORS INTERMITTENTLY OPERATED.

3. TIMED OPERATION OF AERATORS N-2 & S-2 WOULD BE STAGGERED TO ENSURE SOME DISSOLVED OXYGEN IN FEED TO SETTLING TANK AT ALL TIMES.

FIGURE 14. PROPOSED PROCESS MODIFICATIONS FOR EVALUATION IN FUTURE RESEARCH AT TOWN OF OWEGO WPCP NO. 2

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APPENDIX

DAILY NITROGEN DATA

[illegible]

Date	Temperature: Today (°C)	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
1													
2	20	21.8	2.2	294.2	0.9	351.9	3.1	—	—	0.34	4.19	76.9	32.1
3	21	27.5	1.7	401.1	0.7	382.6	2.4	—	—	0.29	4.02	62.5	7.2
4	16	30.9	1.8	401.2	4.6	511.2	8.4	—	—	0.30	6.92	54.5	13.2
5	20	5.5	1.5	36.6	1.8	222.1	5.7	—	—	0.49	4.40	22.1	7.7
6	21	32.2	2.3	401.7	1.9	71.9	4.2	—	—	0.60	4.30	72.1	8.2
7													
8													
9	21	9.7	2.5	294.2	0.6	321.9	3.1	—	—	0.42	4.65	24.2	7.5
10	20	21.4	2.8	321.6	0.5	464.2	3.1	—	—	0.43	4.30	69.6	7.2
11	20	21.4	2.4	321.3	0.6	421.7	3.2	—	—	0.41	4.32	69.2	7.5
12	18	30.5	1.1	371.9	1.9	294.4	2.1	—	—	0.39	0.28	24.5	2.2
13	18	32.9	1.5	377.1	0.6	298.6	2.1	—	—	0.34	0.29	24.1	2.3
14													
15													
16	17	30.1	2.1	301.2	0.5	294.3	2.8	—	—	0.32	0.89	25.6	2.2
17	17	30.9	1.2	298.5	1.3	354.4	2.5	—	—	0.33	2.60	36.5	4.3
18	17	25.9	1.3	325.2	0.5	402.2	1.9	—	—	0.35	2.60	40.2	2.2
19	17	6.3	2.8	301.2	1.9	421.5	1.9	—	—	0.33	2.55	41.8	7.5
20	17	6.8	2.1	302.5	2.2	336.3	2.3	—	—	0.36	4.60	26.7	10.1
21													
22													
23/	17	5.5	2.3	302.3	2.3	327.6	4.3	—	—	0.34	5.60	27.7	10.7
24	17	9.1	2.5	304.5	0.7	328.6	3.2	—	—	0.33	1.80	26.8	8.1
25/	17	6.7	2.4	302.5	0.9	327.8	3.7	—	—	0.30	6.60	27.1	12.6
26	17	8.3	2.3	304.1	1.3	402.6	4.8	—	—	0.38	0.32	42.9	10.7
27	17	27.7	2.1	304.8	1.2	327.5	4.3	—	—	0.34	0.33	26.5	10.6
28													
29													
30	19	32.2	2.9	304.8	0.8	401.8	3.6	—	—	0.45	0.38	42.1	12.5
31													

DAILY NUTRIENT DATA — [illegible]

Date	Rainwater Temp. (°C)	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
2	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
3	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
4	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
5													
6													
7	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
8	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
9	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
10	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
11	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
12													
13													
14	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
15	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
16	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
Plate 3													
17	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
18	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
19													
20													
21	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
22	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
23	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]
24	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26													
27													
28	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Date	Temp. (°C)	Diss-N (mg/l)		NO_3-N (mg/l)		TKN (mg/l)		NO_2-N (mg/l)		NH_3-N (mg/l)		Tot-N (mg/l)	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	20	18.0	2.4	12.0	0.3	45.0	3.0	0.072	Tr.	0.30	1.35	53.2	4.0
2													
3													
4	20	0.0	2.5	26.2	0.4	34.2	2.9	0.050	0.070	0.25	0.65	39.4	3.4
5	20	0.5	2.5	32.1	2.1	40.0	4.0	0.052	Tr.	0.28	0.35	42.0	5.0
6	20	—	2.1	—	0.6	—	3.7	0.060	0.036	0.31	0.65	—	4.4
7	20	21.1	2.3	47.6	2.7	60.3	3.2	—	—	0.35	1.40	68.1	4.6
8	20	15.5	Tr.	44.5	1.1	62.0	1.5	—	—	0.52	1.00	68.0	2.1
9													
10													
11	21	14.5	2.2	24.2	2.5	45.7	4.7	—	—	0.65	0.75	60.1	4.9
12	22	0.2	2.2	28.2	2.1	35.3	5.3	—	—	0.65	1.10	35.2	6.4
13	21	12.1	2.3	37.7	2.2	42.0	4.1	—	—	0.39	1.05	52.2	6.3
14	21	13.9	2.1	29.5	1.3	45.4	3.4	0.030	0.075	0.65	0.80	60.0	6.1
15	21	12.2	2.0	24.0	2.3	49.2	5.3	0.052	0.030	0.92	0.20	67.0	8.3
16													
17													
18	20	12.7	Tr.	32.0	2.0	44.7	3.0	0.052	0.030	0.50	1.35	60.3	6.0
19	20	11.4	1.3	35.2	2.5	40.0	4.7	0.054	0.050	0.30	1.00	60.0	20.0
20	20	0.4	2.4	30.1	1.1	41.0	3.1	0.050	0.050	0.35	0.50	60.3	10.1
21	20	10.0	2.1	27.3	1.1	38.4	2.0	0.054	Tr.	0.30	0.50	50.0	6.1
22	20	11.4	2.0	30.0	0.3	40.0	3.1	0.042	Tr.	0.25	1.00	60.4	7.0
23													
24													
25	21	12.2	1.9	24.2	1.3	35.4	1.4	0.050	0.070	0.12	1.20	50.0	4.0
26	21	11.7	2.1	20.3	0.3	40.0	2.0	0.050	Tr.	0.20	1.60	61.4	5.2
27	20	0.5	2.0	23.0	2.0	32.1	1.2	Tr.	Tr.	0.20	1.40	32.0	4.0
28	20	10.2	1.7	30.1	0.0	34.2	2.1	0.030	0.020	0.22	1.70	50.1	7.4
29	20	12.0	2.0	26.3	0.0	36.2	2.4	0.052	Tr.	0.20	1.70	20.2	7.2
30													
31													

DAILY NITROGEN DATA - EFFLUENT (EF)

Date	Wastewater Temp. (°C)	Org-N (mg/l) Inf.	Org-N (mg/l) Eff.	NH_3-N (mg/l) Inf.	NH_3-N (mg/l) Eff.	TKN (mg/l) Inf.	TKN (mg/l) Eff.	NO_2-N (mg/l) Inf.	NO_2-N (mg/l) Eff.	NO_3-N (mg/l) Inf.	NO_3-N (mg/l) Eff.	Total-N (mg/l) Inf.	Total-N (mg/l) Eff.
1	20	8.0	2.7	23.5	0.3	30.5	3.0	0.050	0.050	0.24	1.60	33.1	7.4
2	21	9.7	2.9	26.7	0.6	36.4	3.4	0.050	0.260	0.30	1.50	36.8	5.1
3	20	8.4	2.4	23.9	1.2	32.3	3.6	0.050	0.775	0.09	1.65	32.5	7.4
4	19	23.3	3.4	25.7	0.3	49.0	3.9	0.750	0.220	0.10	4.60	50.2	8.9
5	20	27.5	3.9	24.8	1.9	52.3	5.3	0.800	5.000	0.20	4.20	53.3	9.5
6													
7													
8	20	22.7	4.1	22.0	2.3	22.7	6.4	0.050	0.160	0.22	1.40	23.0	8.0
Seven-Day													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													

DAILY NUTRIENTS DATA — [illegible]

Date	Wastewater Temp. (°C)	CO_2 (mg/l) Inf.	CO_2 (mg/l) Eff.	NO_3 (mg/l) Inf.	NO_3 (mg/l) Eff.	TKN (mg/l) Inf.	TKN (mg/l) Eff.	PO_4 (mg/l) Inf.	PO_4 (mg/l) Eff.	NH_3 (mg/l) Inf.	NH_3 (mg/l) Eff.	T-alk (mg/l) Inf.	T-alk (mg/l) Eff.
1													
2													
Phase II	Start-Up												
3	M	[illegible]											
4	M												
5	M												
6	M												
7													
8													
9	M												
10	M												
11	M												
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													

[illegible]

Date	Parameter: Temp. (°C)	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1													
2													
3													
4													
5													
6													
7													
8													
9													
Phase IIA													
10	9	37.1	—	33.7	—	42.3	—	0.329	1.266	1.06	3.34	42.3	—
11	8	40.8	1.9	37.2	1.0	55.3	2.9	0.382	1.780	2.42	4.36	37.7	6.6
12	8	38.7	1.9	37.9	1.0	54.6	2.9	0.324	1.804	2.80	5.20	36.3	6.0
13													
14													
15	8	33.3	2.5	36.5	0.7	55.3	2.2	0.060	0.623	1.26	4.50	33.3	7.1
16	8	34.5	2.5	33.6	0.5	38.2	2.0	0.056	0.400	1.26	2.60	33.5	6.3
17	8	34.4	2.0	36.2	0.5	50.4	2.3	0.074	0.530	1.30	4.36	33.0	7.1
18	8	38.2	2.5	38.5	0.7	56.7	2.2	0.054	0.340	1.32	6.00	39.9	20.4
19	8	34.1	2.0	35.5	0.5	39.6	2.5	0.046	0.420	1.30	6.30	33.0	8.3
20													
21													
22	9	34.9	1.7	34.5	0.9	49.3	2.3	0.096	0.770	1.70	6.90	33.1	8.7
23	9	33.1	2.0	33.4	0.3	51.3	2.3	0.066	0.380	1.60	6.60	33.0	8.2
24	9	29.9	1.1	28.5	0.4	40.5	1.5	0.064	0.250	1.66	6.30	40.2	7.9
25	9	33.5	1.3	28.8	0.4	33.5	1.7	0.096	0.720	1.42	6.80	33.0	8.0
26	9	34.8	1.3	34.5	0.2	38.1	1.5	0.062	0.300	1.66	6.60	36.9	20.2
27													
28													
29	10	34.9	1.8	34.1	1.3	39.4	2.9	0.054	0.050	0.40	1.92	38.0	6.5
30	10	32.4	1.5	33.3	0.6	42.3	1.7	0.054	0.030	0.32	0.80	42.7	7.5
31	10	36.9	1.7	32.9	0.6	33.7	2.1	0.062	0.050	0.28	2.25	34.0	6.6

[illegible]

[illegible]

[illegible]

DAILY METERED DATA — [illegible]

Date	Reservoir Temp. (°C)	Org-N (mg/l) Inf.	Org-N (mg/l) Eff.	NH_4-N (mg/l) Inf.	NH_4-N (mg/l) Eff.	TKN (mg/l) Inf.	TKN (mg/l) Eff.	NO_2-N (mg/l) Inf.	NO_2-N (mg/l) Eff.	NO_3-N (mg/l) Inf.	NO_3-N (mg/l) Eff.	Total-N (mg_N/l) Inf.	Total-N (mg_N/l) Eff.
1													
2													
Phase III													
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	—	[illegible]	—	[illegible]	—	[illegible]	—	[illegible]	—	[illegible]	—
6	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	—	[illegible]	—
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8													
9													
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15													
16													
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22													
23													
24	[illegible]	—	—	[illegible]	[illegible]	—	—	—	—	—	—	—	—
25	[illegible]	—	—	[illegible]	[illegible]	—	—	—	—	—	—	—	—
26	[illegible]	—	—	[illegible]	[illegible]	—	—	—	—	—	—	—	—
27	[illegible]	—	—	[illegible]	[illegible]	—	—	—	—	—	—	—	—
28	[illegible]	—	—	[illegible]	[illegible]	—	—	—	—	—	—	—	—
29													
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